

= Lead =

Lead (/ l?d /) is a chemical element in the carbon group with symbol Pb (from Latin : plumbum) and atomic number 82 . It is a soft , malleable and heavy post @-@ transition metal . Freshly cut , solid lead has a bluish @-@ white color that soon tarnishes to a dull grayish color when exposed to air ; the liquid metal has shiny chrome @-@ silver luster . Lead has the highest atomic number of any non @-@ radioactive element (two radioactive elements , namely technetium and promethium , are lighter) , although the next higher element , bismuth , has one isotope with a half @-@ life that is long enough (over one billion times the estimated age of the universe) to be considered stable . Lead 's four stable isotopes each have 82 protons , a magic number in the nuclear shell model of atomic nuclei . The isotope lead @-@ 208 also has 126 neutrons , another magic number , and is hence double magic , a property that grants it enhanced stability : lead @-@ 208 is the heaviest known stable nuclide .

Lead is used in building construction , lead @-@ acid batteries , bullets and shot , weights , as part of solders , pewters , fusible alloys , and as a radiation shield .

If ingested or inhaled , lead and its compounds are poisonous to animals and humans . Lead is a neurotoxin that accumulates both in soft tissues and the bones , damaging the nervous system and causing brain disorders . Excessive lead also causes blood disorders in mammals . Lead poisoning has been documented since ancient Rome , ancient Greece , and ancient China .

= = Physical characteristics = =

= = = Bulk properties = = =

Lead is a bright silvery metal with a very slight shade of blue in a dry atmosphere . It tarnishes on contact with air , forming a complex mixture of compounds whose color and composition depend on conditions , sometimes with significant amounts of carbonates and hydroxycarbonates . Lead 's characteristic properties include high density , softness , ductility , malleability , poor electrical conductivity compared to other metals , high resistance to corrosion , and ability to react with organic chemicals .

Various traces of other metals significantly change its properties : adding small amounts of antimony or copper increases the lead alloy 's hardness and improves resistance to sulfuric acid corrosion . Some other metals , such as cadmium , tin , and tellurium , improve hardness and fight metal fatigue . Sodium and calcium also have this ability , but they reduce the alloy 's chemical stability . Finally , zinc and bismuth simply impair the corrosion resistance . Adding small amounts of lead improves the ductility of steel , but lead impurities mostly worsen the quality of industrial materials .

Lead has only one common allotrope , which is face @-@ centered cubic , with the length of an edge of a unit cell being 349 pm . Unlike the other elements in its group , it does not have a diamond cubic allotrope . At 327 @-@ 5 ° C (621 @-@ 5 ° F) , lead melts ; the melting point exceeds that of tin (232 ° C , 449 @-@ 5 ° F) , but is significantly below that of germanium (938 ° C , 1721 ° F) . The boiling point of lead is 1749 ° C (3180 ° F) , below those of both tin (2602 ° C , 4716 ° F) and germanium (2833 ° C , 5131 ° F) . Densities increase down the group : the values of germanium and tin (5 @-@ 23 and 7 @-@ 29 g · cm⁻³ , respectively) are significantly below that of lead : 11 @-@ 32 g · cm⁻³ .

= = = Isotopes = = =

Lead has four observationally stable isotopes , lead @-@ 204 , lead @-@ 206 , lead @-@ 207 , and lead @-@ 208 . The relative multitude of its stable isotopes relies on the fact that lead 's atomic number of 82 is even . With its high atomic number , lead is the second @-@ heaviest element that occurs naturally in the form of isotopes that could be treated as stable for any practical applications :

bismuth has a higher atomic number of 83, but its only primordial isotope was found in 2003 to be actually very slightly radioactive. The four stable isotopes of lead could theoretically undergo alpha decay to isotopes of mercury with release of energy as well, but this has not been observed for any of them: accordingly, their predicted half-lives are extremely long, ranging up to over 10¹⁰⁰ years. As such, lead is often quoted as the heaviest stable element.

Three of these isotopes also found in three of the four major decay chains: lead-206, lead-207, and lead-208 are the final decay products of uranium-238, uranium-235, and thorium-232, respectively; the decay chains are called the uranium series, actinium series, and thorium series, respectively. Since the amounts of them in nature depend also on the presence of other elements, the isotopic composition of natural lead varies between samples: in particular, the relative amount of lead-206 may vary between 20% and 84%, and the relative amount of lead-208 may vary between 4% and 52% in normal samples to 90% in thorium ores. (For this reason, the atomic weight of lead is given with such imprecision, to only one decimal place.) As time passes, relative amounts of lead-206 and lead-207 to that of lead-204 increase, since the former two are supplemented by radioactive decay of heavier elements and the latter is not; this allows for lead-lead dating. Analogously, as uranium decays (eventually) into lead, their relative amounts change; this allows for uranium-lead dating.

Apart from the stable isotopes, which make up almost all of lead that exists naturally, there are trace quantities of a few radioactive isotopes. One of them is lead-210; although it has a half-life of 22.3 years, a period too short to allow any primordial lead-210 to still exist, some small non-primordial quantities of it occur in nature, because lead-210 is found in the uranium series: thus, even though it constantly decays away, its amount is also constantly regenerated by decay of its parent, polonium-214, which, while also constantly decaying, is also supplied by decay of its parent, and so on, all the way up to original uranium-238, which has been present for billions of years on Earth. Lead-210 is particularly well known for helping to identify ages of samples containing it, which is performed by measuring lead-210 to lead-206 ratios (both isotopes are present in a single decay chain). Lead-214 is also present in the decay chain of natural uranium-238, lead-212 is present in that of natural thorium-232, and lead-211 is present in that of natural uranium-235; therefore, traces of all three of these isotopes exist naturally as well. Lastly, very minute traces of lead-209 are also present from the cluster decay of radium-223, one of the daughter products of natural uranium-235. Hence, natural lead consists of not only the four stable isotopes, but also minute traces of another five short-lived radioisotopes.

In total, thirty-eight isotopes of lead have been synthesized, those with mass numbers of 178 to 215. Lead-205 is the most stable radioisotope of lead, with a half-life of around 1.5 × 10⁷ years. The second most stable radioisotope is the synthetic lead-202, which has a half-life of about 53,000 years, longer than any of the natural trace radioisotopes. Additionally, 47 nuclear isomers (long-lived excited nuclear states), corresponding to 24 lead isotopes, have been characterized. The longest-lived isomer is lead-204m (half-life of about 1.1 hours).

== Chemical characteristics ==

A lead atom has 82 electrons, arranged in an electronic configuration of [Xe] 4f¹⁴5d¹⁰6s²6p². The first and second ionization energies (energies required to remove an electron from a neutral atom and an electron from a resulting singly charged ion) of lead combined are close to those of tin, its upper group 14 neighbor; this proximity is caused by the 4f shell (no f shell is present in previous group 14 elements atoms) and the thereby following lanthanide contraction. However, the first four ionization energies of lead combined exceed those of tin, opposite to what the periodic trends would predict. For that reason, unlike tin, lead is reluctant to form the +4 oxidation state in inorganic compounds.

Such unusual behavior is rationalized by relativistic effects, which are increasingly stronger closer

to the bottom of the periodic table ; one of such effects is the spin ? orbit interaction , particularly the inert pair effect , which stabilizes the 6s orbital . The inert pair effect in lead comes from the great difference in electronegativity between lead and the anions (oxide , halides , nitrides) , which results in positive charge on lead and then leads to a stronger contraction of the 6s orbital than the 6p orbital , making the 6s orbital rather inert . (However , this is not applicable to compounds in which lead forms covalent bonds ; as such , lead , similarly to carbon , is dominantly tetravalent in organolead compounds .) The spin ? orbit interaction not only stabilizes the 6s electron levels , but also two of the six 6p levels ; and lead has just two 6p electrons . This effect takes part in making lead slightly less reactive chemically .

The figures for electrode potential show that lead is only slightly easier to oxidize than hydrogen . Lead thus can dissolve in acids , but this is often impossible due to specific problems (such as the formation of insoluble salts) . Electronegativity , although often thought to be constant for each element , is a variable property ; lead shows a high electronegativity difference between values for lead (II) and lead (IV) ? 1 @. @ 87 and 2 @. @ 33 , accordingly . This marks the reversal of the trend of stability of the + 4 oxidation state in group 14 down the group from increasing to decreasing ; tin , for comparison , has electronegativities of 1 @. @ 80 and 1 @. @ 96 .

= = = Reactivity = = =

Powdered lead burns with a bluish @-@ white flame . As with many metals , finely divided powdered lead exhibits pyrophoricity . Bulk lead released to the air forms a protective layer of insoluble lead oxide , which covers the metal from undergoing further reactions . Other insoluble compounds , such as sulfate or chloride , may form the protective layer if lead is exposed to a different chemical environment .

Fluorine reacts with lead at room temperature , forming lead (II) fluoride . The reaction with chlorine is similar , although it requires heating : the chloride layer diminishes the reactivity of the elements . Molten lead reacts with all the chalcogens .

Presence of carbonates or sulfates results in the formation of insoluble lead salts , which protect the metal from corrosion . So does carbon dioxide , as the insoluble lead carbonate is formed ; however , an excess of the gas leads to the formation of the soluble bicarbonate , which makes the use of lead pipes dangerous . Water in the presence of oxygen attacks lead to start an accelerating reaction . Lead also dissolves in quite concentrated alkalis (? 10 %) because of the amphoteric character and solubility of plumbites .

The metal is normally not attacked by sulfuric acid ; however , concentrated acid does dissolve lead thanks to complexation . Lead does react with hydrochloric acid , albeit slowly , and nitric acid , quite actively , to form nitrogen oxides and lead (II) nitrate . Organic acids , such as acetic acid , also dissolves lead , but this reaction requires oxygen as well .

= = = Inorganic compounds = = =

In a vast majority of its compounds , lead occurs in oxidation states + 2 or + 4 . Lead (II) compounds are normally ionic but lead (IV) compounds are often covalent . Even the strongest oxidizing elements (oxygen , fluorine) oxidize lead to only lead (II) initially .

= = = Lead (II) = = =

Most inorganic compounds that lead forms are lead (II) compounds . This includes binary compounds ; lead forms such compounds with many nonmetals , but not with all of them , as for example there is no known lead carbide .

Even though most lead (II) compounds are ionic , they are not as ionic as those of many other metals . In particular , many lead (II) compounds are water @-@ insoluble . In solution , lead (II) ions are colorless , but under specific conditions , lead is capable of changing its color . Unlike tin (II) ions , these do not react as reducing agents in solution .

Lead monoxide exists in two allotropes, red α -PbO and yellow β -PbO, the latter being stable only from around 488 °C. It is the most commonly applicable compound of lead. However, its hydroxide counterpart, lead (II) hydroxide, is not capable of existence outside solutions; in solution, it is known to form anions, plumbites. Lead commonly reacts with the heavier chalcogens. Lead sulfide can only be dissolved in strong acids. It is a semiconductor, a photoconductor, and an extremely sensitive infrared radiation detector. A mixture of the monoxide and the monosulfide when heated forms the metal. The other two chalcogenides are photoconducting as well.

Lead dihalides are known and well characterized; this refers to not only the binary halides (even including the diastatide), but also mixed ones, such as PbFCl, etc. The difluoride is the first ionically conducting compound to have been discovered. The other dihalides decompose on exposure to ultraviolet or visible light, especially notably for the diiodide. There are anion counterparts for the heavier three dihalides, such as PbCl₄²⁻.

6. Many pseudohalides are also known.

==== Lead (IV) =====

Few lead (IV) compounds are known. Inorganic lead (IV) compounds are typically strong oxidants or exist only in highly acidic solutions. Lead (II) oxide gives a mixed oxide on further oxidation, Pb

3O

4. It is described as lead (II, IV) oxide, or structurally 2PbO · PbO

2, and is the best known mixed valence lead compound. Lead dioxide is a strong oxidizing agent, capable of oxidizing hydrochloric acid. Like lead monoxide, lead dioxide is capable of forming anions, plumbates. Lead tetrafluoride, a yellow crystalline powder, is stable, but less stable than the difluoride. Lead tetrachloride decomposes at room temperature, lead tetrabromide is less stable still and the existence of lead tetraiodide is questionable. Lead disulfide, like the monosulfide, is a semiconductor. Lead (IV) selenide is also known.

==== Other oxidation states =====

A few compounds exist in oxidation states other than +2 and +4, but they do not have a great impact on lead chemistry from either theoretical or industrial perspective. Lead (III) may be obtained under specific conditions as an intermediate between lead (II) and lead (IV), in larger organolead complexes rather than by itself. This oxidation state is not specifically stable, as the lead (III) ion (as well as, consequently, larger complexes containing it) is a radical; the same applies for lead (I), which can also be found in such species. Negative oxidation states can occur as Zintl phases, as either free lead anions, for example, in Ba

2Pb, with lead formally being lead (IV), or cluster ions, for example, in a Pb₅²⁻

ion, where two lead atoms are lead (I) and three are lead (0): this illustrates lead's proclivity towards catenation, an ability shared with tin.

==== Organolead =====

Since lead is a heavier carbon homolog, it shares with carbon the property of being able to build long chains of atoms, bonded via single or multiple bonds: catenation. Lead may therefore behave in a similar way to carbon with regards to covalent chemistry. Lead atoms can build metal-metal bonds of order up to three, although lower orders are also possible. Alternatively, lead is also known to build bonds to carbon; the carbon-lead bonds are covalent, and compounds containing such bonds thus resemble typical organic compounds. Compound containing the lead-carbon bond are called organolead compounds. In general, such compounds are not very stable chemically.

The simplest lead analog of an organic compound is plumbane, the lead analog of methane. It is unstable against heat, decaying in heated tubes, and thermodynamically; in general, little is

known about chemistry of plumbane, as it is so unstable. A lead analog of the next alkane, ethane, is not known. Two simple plumbane derivatives, tetramethyllead and tetraethyllead, are the best known organolead compounds. These compounds are relatively unstable against heating; tetraethyllead starts to decompose at only 100 °C (210 °F) as well as sunlight or ultraviolet light. General oxidizing nature of organolead compounds find its use in chemistry: tetraethyllead is produced in larger quantities than any other organometallic compound; lead tetraacetate is an important laboratory reagent for oxidation in organic chemistry. Other organolead compounds, including homologs of the said compounds, are still less chemically stable.

Lead readily forms an equimolar alloy with sodium metal that reacts with alkyl halides to form organometallic compounds of lead such as tetraethyllead. Plumbane may be obtained in a reaction between metallic lead and atomic (not molecular) hydrogen. Atoms of chlorine or bromine displace alkyls in tetramethyllead and tetraethyllead; hydrogen chloride, a by-product of the previous reaction, further reacts with the halogenated molecules to complete mineralization: a chemical reaction or a series of reactions transforming an organic compound into an inorganic one of the original compounds, yielding lead dichloride.

== Origin and occurrence ==

== In space ==

Primordial lead: the isotopes lead-204, lead-206, lead-207, and lead-208 were created by the s-process and the r-process. The letter "s" stands for "slow" or "slow neutron capture", and the letter "r" stands for "rapid neutron capture": in the s-process another capture takes a long time, centuries or millennia, while the r-process takes only tens of seconds to result in a heavy nuclide of lead's mass. In the s-process, a nucleus in a star captures another slow neutron, and if the resulting nucleus is unstable, it typically undergoes a beta decay to become an element of the next atomic number. Lead-204 is created from short-lived thallium-204; on capturing another neutron, it becomes lead-205, which, while unstable, is stable enough to generally last longer than a capture takes (its half-life is around 15 million years). Further captures result in lead-206, lead-207, and lead-208. On capturing another neutron, lead-208 becomes lead-209, which quickly decays into bismuth-209, which on capturing another neutron becomes bismuth-210, which either undergoes an alpha decay to result in thallium-206, which would beta decay into lead-206, or a beta decay to yield polonium-210, which would inevitably alpha decay into lead-206 as well, and the cycle ends at lead-206, lead-207, lead-208, and bismuth-209. As a result, relative abundances of the three have stable lead isotopes are multiplied by a "cycling factor", which depends on the conditions of the process. Furthermore, lead-208 and bismuth-209 have a very low cross section towards neutron capture because of their closed neutron shell at neutron number 126. Lead and bismuth are thus very common in stars, in which nucleosynthesis mostly happens through the s-process.

Apart from the s-process, the latter three isotopes have been synthesized as a result of the r-process (lead-204 is not produced in this manner because its isobar mercury-204 is stable, and it is not formed as a decay product of r-process products). The r-process happens in mediums of great electron density. In such conditions, beta decay is blocked, because the high electron density fills all available free electron states up to a Fermi energy which is greater than the energy of nuclear beta decay. But nuclear capture of those free neutrons can still occur, and it causes neutron enrichment of matter. This results in an extremely high density of free neutrons which cannot decay, and, correspondingly, a large neutron flux and high temperatures, which is the reason why neutron capture occurs much faster than beta decay. However, the r-process does not directly form as much lead as the s-process, because neutron-rich nuclei with mass numbers 206-208 that would decay to lead are not magic, unlike those that reach the closed neutron shell at neutron number 126 and decay to the platinum group metals around mass

number 194 . This effect is nevertheless masked , because these lead isotopes are also located at the end of three major decay chains (see above) , they are created by the decay of the heavier elements , which are also created by the r process . Nuclides with mass numbers between 210 and 231 inclusive , as well as 233 and 234 (polonium through actinium , as well as protactinium) , quickly undergo alpha and beta decay to stable lead and bismuth isotopes . However , nuclides with mass numbers 232 as well as 235 and above soon decay to the extremely long lived isotopes of thorium and uranium , which decay very slowly to lead . Hence , the amount of lead in the universe is still slowly increasing .

The isotopes at the end of the chains make up around 98 % lead in the universe , with non radiogenic lead ^{204}Pb making up slightly less than two percent . Lead is not an abundant element in general ? its per particle abundance in the Universe is 0.06 ppb ? still , it is an order of magnitude more abundant than mercury , and further exceeds those of most other elements of similar atomic numbers . After element 40 (zirconium) , no element is at least twofold as abundant as lead , and there is no element as abundant as lead starting after element 56 (barium) . Lead is three times as abundant as platinum , ten times as mercury , and twenty times as gold . Per mass , lead 's abundance is 10 ppb ? the difference between the per mass and per particle abundances is justified by mass difference between lead isotopes and the most common elements : the most common nuclide in the Universe , hydrogen ^1H , has a mass of approximately one atomic mass unit , while those of lead isotopes have masses of over 200 atomic mass units .

== On Earth ==

Since lead commonly reacts with sulfur (see above) , it is classified as a chalcophile using the Goldschmidt classification . Lead is likely to form minerals that do not sink into the core but that stay above on Earth in its crust , even though without sinking deep into it . Lead 's abundance in the Earth 's crust is 16 ppm . This results in a great availability of lead minerals and easy extraction of the metal ; for this reason , the mineral form of its sulfide , galena , has been known for millennia , as was the metal itself (see below) . Lead 's pronounced chalcophilic character is close to those of zinc and copper ; as such , it is usually found in ore and extracted together with these metals . Metallic lead does occur in nature , but it is rare . As a result of lead 's chemistry , it occurs in primary minerals exclusively as lead (II) , unlike tin , which always occurs as tin (IV) . Lead deposits can be hydrothermal vein , impregnation , and replacement deposits ; volcanogenic sedimentary deposits ; and hydrothermal or marine sedimentary deposits . World resources of lead exceed 2 billion tons . Massive resources are located in Australia , China , Ireland , Mexico , Peru , Portugal , Russia , and the United States . World reserves ? resources ready to be mined for which that would be economically feasible ? totaled 89 million tons in 2015 , of which Australia had 35 million , China had 15.8 million , and Russia had 9.2 million .

The main lead mineral is galena (PbS) . Galena is mostly found with other minerals , mostly zinc ores . Most other lead minerals are normally related to galena in some way ; for example , boulangerite , $\text{Pb}_{12}\text{Sb}_4\text{S}_{14}$

5Sb

4S

11 , is a mixed sulfide derived from galena ; anglesite , PbSO_4

4 , is a product of galena oxidation ; cerussite or white lead ore , PbCO_3

3 , is a decomposition product of galena . Zinc , copper , arsenic , tin , antimony , silver , gold , and bismuth are common impurities in lead minerals .

Typical background concentrations of lead do not exceed 0.1 $\mu\text{g} / \text{m}^3$ in the atmosphere ; 100 mg / kg in soil ; 5 $\mu\text{g} / \text{L}$ in freshwater and seawater .

== History ==

Lead has been commonly used for thousands of years because it is widespread , easy to extract ,

and easy to work with . It is highly malleable and easily smeltable . Metallic lead beads dating back to 7000 ? 6500 BCE , if not before that , have been found in Asia Minor ; this indicates lead was the first metal to be ever smelted . Since then , the metal has been used by many ancient peoples . A major reason for the spread of lead production was its association with silver , which may be obtained by burning galena , a widespread lead mineral . The Ancient Egyptians are thought to have used lead for sinkers in fishing nets , in glazes , glasses and enamels , and for ornaments ; they also were the first to use lead for cosmetics , a use that would continue through millennia to Ancient Greece and far beyond . Various civilizations of the Fertile Crescent used lead as a writing material , as currency , and for construction . The Ancient Chinese used lead as a stimulant in the royal court , a currency , and a contraceptive ; lead also had a few uses , such as making amulets , for the Indus Valley civilization and the Mesoamericans . Peoples of eastern and southern Africa are known to exercise wire drawing .

Lead mines were worked in 2000 BCE in the Iberian peninsula by the Phoenicians ; and also in Athens , Carthage , and Sicily . Lead was mined in Ancient China before 1000 BCE . With the development of mining and its territorial expansion in Europe and across the Mediterranean , Rome became the greatest producer of lead during the classical era , with an estimated annual output equaling 80 @, @ 000 tonnes . The Romans obtained lead mostly as a by @-@ product of extensive silver smelting . Lead mining occurred in Central Europe , Britain , the Balkans , Greece , Anatolia , and Hispania , which alone accounted for 40 % of world production . Lead was used for making water pipes in the Roman empire and consequently the Latin word for the metal , plumbum , was the origin of the English word " plumbing " and its derivatives ? even though some Romans , such as Vitruvius , were able to recognize its danger for health . Nevertheless , a number of researchers suggest lead poisoning was one of the reasons behind the fall of Rome . Lead poisoning ? a condition in which one becomes dark and cynical ? was called " saturnine " , after the ghoulish god of Saturn ; the metal was also considered the father of all metals . It was easily available in the Roman society , and as such , its social status was low .

During the ancient and classical eras , (and even far beyond them , until the 17th century) , tin was often not distinguished from lead or seen as a different kind of the metal that lead is : Romans called lead plumbum nigrum (literally , " black lead ") , while tin was called plumbum candidum (literally , " bright lead ") . Their association through history can also be seen in other languages : the word olovo in Czech translates to " lead " , but in Russian the cognate ????? (olovo) means " tin " . In addition to that , lead also bore a close relation to antimony : Both elements commonly occur as sulfides (galena and stibnite) , often together . Pliny declared stibnite would give lead on heating , whereas the mineral on heating actually produces antimony . The originally South Asian surma ? " galena " in English ? spread across Asia with that meaning , and also gave its name to antimony in a number of Central Asian languages , as well as Russian .

Lead plumbing in Western Europe may have been continued beyond the fall of the Western Roman Empire into the medieval era , but lead mining in Europe in general fell into decline , and the largest lead production was conducted in South and East Asia , where lead output underwent a strong growth . In European alchemy , lead continued its status of the oldest metal and its association with Saturn ? this time , the planet named after the Roman god rather than the god himself . Alchemists accordingly used Saturn 's symbol (the scythe , ?) to refer to lead . During the period , lead has become increasingly more used as for wine adulteration . This practice was declared forbidden in 1498 by a papal bull , but it continued long past the date , being a reason of various mass poisonings up to late 18th century . In the wake of the Renaissance , the printing press was invented , and lead served as a key material for its parts , starting with the Johannes Gutenberg 's press ; however , lead dust also was commonly inhaled by operators , causing lead poisoning . Additionally , firearms were invented approximately at the same time , and lead , despite its expense over iron , became a chief material for making bullets , because it made less damage to iron gun barrels , had a higher density (which allowed better retaining velocity and energy) , and its lower melting point made production much easier : bullets could be made on wooden fire . Lead was extensively used in cosmetics at the time in Western Europe by the aristocracy , as whitened faces were seen as a sign of modesty . The practice eventually expanded to white wigs and eyeliners , and it only faded

out with the French Revolution in the late 18th century ; one effect of such prolonged contacts with lead was teeth rotting and teeth replacements often were also made of lead (which temporarily gave sweet breath) , inducing further damage to the organism . (A similar fashion appeared in Japan in the 18th century with the emergence of the geishas , with the practice continuing long into the 20th century and the white face becoming a " symbol of a Japanese woman " ; lead was commonly used as a face whitener .)

In the New World , lead was first produced soon after the European settlers had arrived ; the earliest recorded lead production dates to 1621 , in the Colony of Virginia that had been founded fourteen years earlier . In Australia , mining was introduced by the colonists as well , and they opened the first mine on the continent ? a lead mine ? in 1841 . However , centuries before the Europeans were able to start the colonization of Africa in the late 19th century , lead mining was known in the Benue Trough and the lower Congo basin , where lead was used for trade with the Europeans and as a currency .

In the second half of the 18th century , Britain and later continental Europe and then the United States entered the Industrial Revolution . During the period , lead mining proved important ; the Industrial Revolution was the first time to have greater lead production rates than those of Rome . Britain was the leading producer during the period , losing the status of the greatest producer by the mid @-@ 19th century with depletion of its mines and development of lead mining in Germany , Spain , and the United States . The United States took the lead by 1900 ; other non @-@ European nations ? in particular , Canada , Mexico , and Australia ? started their massive lead production , and by 1900 , Europe 's output of lead fell below that elsewhere . A great share of demand of lead came from plumbing and painting ? lead paints had been invented and regularly used ; with invention of gasoline in late 19th century , lead was extensively used as an additive . At this time , more people ? the working class ? contacted the metal , and this led to the increase of the numbers of those poisoned by lead . This also led to research of effects of lead intake : lead was proven to be more dangerous in its fume form than as a solid metal ; lead poisoning and gout were linked (Alfred Baring Garrod noted a third of his gout patients was plumbers and painters) ; effects of chronic ingestion of lead , including mental disorders , were all studied in the 19th century . The first political acts to decrease the degree of lead poisoning in factories followed in the 1870s and 1880s in the United Kingdom .

Further evidence of the threat lead posed to human organisms were revealed in the late 19th and early 20th centuries ? mechanisms of the harm were better realized , and lead blindness was documented ? and countries in Europe and the United States started efforts to reduce the amount of lead a regular person contacts with . The last major innovation to impose contact with lead on humans was adding tetraethyllead to gasoline , invented in the United States in 1921 ; it was phased out in the U.S. and the European Union by 2000 . Most European countries banned usage of lead paint for interiors by 1930 . The result of many regulations and bans put on lead products was significant : in the last quarter of the 20th century , percentage of people with excessive lead blood levels dropped from over three quarters of the population to slightly over two percent in the U.S. By the end of the 20th century , the main good made of lead was the lead ? acid battery , which possesses no direct threat to humans . That allowed for a consistent lead production in the industrialized countries . From 1960 to 1990 , lead output in the Western Bloc grew by 31 % . The share of the world 's lead production of the Eastern Bloc increased from 10 % and 30 % from 1950 to 1990 , with the Soviet Union being world 's largest producer during the mid- and late 1970s and the 1980s , and China started a massive lead production in the late 20th century . Unlike the European communist countries , China was largely unindustrialized by mid @-@ 20th century ; in 2004 , China surpassed Australia as the largest producer of lead . However , in part similarly to the European industrialization , lead does have a negative effect on the global health in the country .

= = Production = =

Production and consumption of lead is increasing worldwide . Lead production generally is divided into two major categories , primary and secondary : the primary production is the production from

concentrate from the previously mined ores , and the secondary production is the production from scrap . In 2013 , 4 @. @ 74 million metric tons came from the primary production , and 5 @. @ 74 million tons came from secondary production . The top mining countries for lead in 2013 were China , Australia , Russia , India , Bolivia , Sweden , North Korea , South Africa , Poland , and Ireland . The top lead producing countries were China , United States , India , South Korea , Germany , Mexico , United Kingdom , Canada , Japan , and Australia . According to the International Resource Panel 's Metal Stocks in Society report of 2010 , the global per capita stock of lead in use in society is 8 kg . Much of this is in more developed countries (20 ? 150 kg per capita) rather than less developed countries (1 ? 4 kg per capita) .

= = = Primary production = = =

Most lead ores contain only a very low percentage of lead , which must be concentrated during processing . During initial ore processing , ores typically undergo crushing , dense @-@ medium separation , grinding , froth flotation , and drying of the resulting concentrate . The resulting concentrate is the initial quantitative metric of mined lead . Sulfide ores are roasted , producing primarily lead oxide and a mixture of sulfates and silicates of lead and other metals contained in the ore . Lead oxide from the roasting process is reduced in a coke @-@ fired blast furnace to the metal . Sulfate concentrate is more common for subsequent lead production than oxide concentrate ; it commonly has a lead content fraction of 50 % ? 60 % , occasionally varying to up to 30 % or 80 % .

Additional layers separate in the process and float to the top of the metallic lead . These are slag (silicates containing 1 @. @ 5 % lead) , matte (sulfides containing 15 % lead) , and speiss (arsenides of iron and copper) . These wastes contain concentrations of copper , zinc , cadmium , and bismuth that can be recovered economically , as can their content of unreduced lead .

Metallic lead that results from the roasting and blast furnace processes still contains significant contaminants of arsenic , antimony , bismuth , zinc , copper , silver , and gold . The melt is treated in a reverberatory furnace with air , steam , and sulfur , which oxidizes the contaminants except silver , gold , and bismuth . The oxidized contaminants are removed by drossing , where they float to the top and are skimmed off . Since lead ores contain significant concentrations of silver , the smelted metal also is commonly contaminated with silver . Metallic silver as well as gold is removed and recovered economically by means of the Parkes process , in which zinc is added to lead and adsorbs silver , which dissolves in zinc many times more actively than in lead . Desilvered lead is freed of bismuth according to the Betterton @-@ Kroll process by treating it with metallic calcium and magnesium , which forms a bismuth dross that can be skimmed off . Very pure lead can be obtained by processing smelted lead electrolytically by means of the Betts process . The process uses anodes of impure lead and cathodes of pure lead in an electrolyte of silica fluoride . Once electrical potential is applied , impure lead at the anode dissolves and then plates out in the cathode , while the impurities remain in the solution .

= = = Secondary production = = =

= = Applications = =

Contrary to popular belief , pencil leads in wooden pencils have never been made from lead . The term comes from the Roman stylus , called the penicillus , a small brush used for painting . When the pencil originated as a wrapped graphite writing tool , the particular type of graphite being used was named plumbago (lit. act for lead , or lead mockup) .

= = = Elemental form = = =

Lead metal has a number of mechanical properties that make using it advantageous in comparison with many alternatives : high density , low melting point , ductility , and relative inertness against

oxygen attacks . While many metals are superior to lead in some of these aspects , lead is also more common than most of these metals ; moreover , lead minerals are easier to mine and then lead is easier to extract from its ores than many other metals , which makes the resulting metal relatively inexpensive . One disadvantage of using lead , however , is its chemical toxicity , and it has been a reason why lead was or is being phased out for some uses .

Lead has been used for bullets since their invention (see above) ; however , with the development of firearms , round bullets became pointed and later , lead was jacketed with , for example , copper . The low melting point makes casting of lead easy , and therefore small arms ammunition and shotgun pellets can be cast with minimal technical equipment . It is also inexpensive and denser than other common metals . Lead is sometimes alloyed with tin or antimony : this increases the cost and time of making the bullet , but increasing the hardness of the bullet , this makes the bullet more effective against hard targets , eases the tension on the gun barrel and does not contaminate it with lead , as simple lead bullets do . However , concerns have been raised over whether lead bullets used for hunting can damage the environment .

Because of its high density and resistance to corrosion , lead is used for the ballast keel of sailboats . Its high density allows it to counterbalance the heeling effect of wind on the sails while at the same time occupying a small volume and thus offering the least underwater resistance . For the same reason , it is used in scuba diving weight belts to counteract the diver 's natural buoyancy and that of his equipment .

Lead is alloyed with copper and its alloys (namely , brass and bronze) to increase their machinability and to reduce machine tool wear . Lead does not form a solid solution with copper and is found as granules within copper . It acts as a lubricant in copper ; in low concentrations , it also acts as a chip breaker .

It is also used to form glazing bars for stained glass or other multi @-@ lit windows . The practice has become less common , not for danger but for stylistic reasons . Lead , or sheet @-@ lead , is used as a sound deadening layer in some areas in wall , floor and ceiling design in sound studios where levels of airborne and mechanically produced sound are targeted for reduction or virtual elimination . It is the traditional base metal of organ pipes , mixed with varying amounts of tin to control the tone of the pipe .

Lead has many uses in the construction industry (e.g. , lead sheets are used as architectural metals in roofing material , cladding , flashing , gutters and gutter joints , and on roof parapets) . Detailed lead moldings are used as decorative motifs used to fix lead sheet . Lead is still widely used in statues and sculptures . Lead is often used to balance the wheels of a car ; this use is being phased out in favor of other materials for environmental reasons .

Apart from its mechanical properties , lead is also useful in batteries , namely lead ? acid batteries . The reactions in the battery between lead , lead dioxide , and sulfuric acid provides a reliable source of voltage . This , since lead in batteries undergoes no direct contact with humans (and thus no toxicity) , is a use not threatened by toxicity concerns , and has been the largest use of lead in early 21st century .

Lead is also used as electrodes in the process of electrolysis . It is used in solder for electronics , although this usage is being phased out by some countries to reduce the amount of environmentally hazardous waste , and in high voltage power cables as sheathing material to prevent water diffusion into insulation . Lead is one of three metals used in the Oddy test for museum materials , helping detect organic acids , aldehydes , and acidic gases . It is also used as shielding from radiation (e.g. , in X @-@ ray rooms) . Molten lead is used as a coolant (e.g. , for lead cooled fast reactors) .

= = = Compounds = = =

Lead compounds are used as a coloring element in ceramic glazes , notably in the colors red and yellow .

Lead tetraacetate (LTA) and lead dioxide have been used as oxidizing agents in organic chemistry . Geminal diols are cleaved to a pair of carbonyl compounds by stoichiometric LTA . LTA also is a selective oxidant of 5 @-@ methyl groups in 5 @-@ methylpyrrole @-@ 2 @-@ carboxylic esters ,

leading to 5 acetoxyethyl groups or 5 formyl groups with one or two equivalents of oxidant, respectively, to provide important intermediates for porphyrin synthesis.

Lead is frequently used in polyvinyl chloride (PVC) plastic, which coats electrical cords.

Lead is used in some candles to treat the wick to ensure a longer, more even burn. Because of the dangers, European and North American manufacturers use alternatives such as zinc. Lead glass is composed of 12–28% lead oxide. It changes the optical characteristics of the glass and reduces the transmission of ionizing radiation.

Some artists using oil-based paints continue to use lead carbonate white, citing its properties in comparison with the alternatives. Tetraethyl lead is used as an anti-knock additive for aviation fuel in piston-driven aircraft. Lead-based semiconductors, such as lead telluride, lead selenide and lead antimonide are finding applications in photovoltaic (solar energy) cells and infrared detectors.

== Biological and environmental effects ==

=== Biological ===

Lead is a highly poisonous metal (whether inhaled or swallowed), affecting almost every organ and system in the body. The component limit of lead (1 mg/g) is a test benchmark for pharmaceuticals, representing the maximum daily intake an individual should have. Even at this level, a prolonged intake can be hazardous to human beings. Much of its toxicity comes from how Pb^{2+} ions are confused for Ca^{2+} ions, and lead as a result gets into bones.

In the human body, lead inhibits heme synthesis and ferrochelatase, preventing both heme synthesis and the incorporation of iron into protoporphyrin IX, the final step in heme synthesis. This causes ineffective heme synthesis and subsequent microcytic anemia. At lower levels, it acts as a calcium analog, interfering with ion channels during nerve conduction. This is one of the mechanisms by which it interferes with cognition. Acute lead poisoning is treated using disodium calcium edetate: the calcium chelate of the disodium salt of ethylenediaminetetraacetic acid (EDTA). This chelating agent has a greater affinity for lead than for calcium and so the lead chelate is formed by exchange. This is then excreted in the urine leaving behind harmless calcium. According to the Agency for Toxic Substances and Disease Registry, a small amount of ingested lead (1%) will store itself in bones, and the rest will be excreted by an adult through urine and feces within a few weeks of exposure. However, only about 32% of lead will be excreted by a child.

Exposure to lead and lead chemicals occurs primarily through ingestion, to a lesser extent through inhalation and occasionally by direct contact.

Ingestion of lead-based paint is the major source of lead exposure for children. As lead paint deteriorates, it peels, is pulverized into dust and then enters the body through hand-to-mouth contact or through contaminated food, water or alcohol. Ingesting certain home remedy medicines may also expose people to lead or lead compounds. Lead can be ingested through fruits and vegetables contaminated by high levels of lead in the soils they were grown in. Soil is contaminated through particulate accumulation from lead in pipes, lead paint and residual emissions from leaded gasoline that was used before the Environment Protection Agency issued the regulation in 1980. The use of lead for water pipes is problematic in areas with soft or (and) acidic water. Hard water forms insoluble layers in the pipes while soft and acidic water dissolves the lead pipes.

Inhalation is the second major pathway of exposure, especially for workers in lead-related occupations. Almost all inhaled lead is absorbed into the body, the rate is 20–70% for ingested lead; children absorb more than adults.

Dermal exposure may be significant for a narrow category of people working with organic lead compounds, but is of little concern for general population, as most countries stopped using leaded gasoline by 2007. The rate of skin absorption is also low for inorganic lead.

The main target for lead toxicity is the nervous system , both in adults and children . Long @-@ term exposure of adults can result in decreased performance in some tests that measure functions of the nervous system . Long @-@ term exposure to lead or its salts (especially soluble salts or the strong oxidant PbO_2) can cause nephropathy , and colic @-@ like abdominal pains . It may also cause weakness in fingers , wrists , or ankles . Lead exposure also causes small increases in blood pressure , particularly in middle @-@ aged and older people and can cause anemia . Exposure to high lead levels can cause severe damage to the brain and kidneys in adults or children and ultimately cause death . In pregnant women , high levels of exposure to lead may cause miscarriage . Chronic , high @-@ level exposure has been shown to reduce fertility in males . Lead also damages nervous connections (especially in young children) and causes blood and brain disorders . Lead poisoning typically results from ingestion of food or water contaminated with lead , but may also occur after accidental ingestion of contaminated soil , dust , or lead @-@ based paint . It is rapidly absorbed into the bloodstream and is believed to have adverse effects on the central nervous system , the cardiovascular system , kidneys , and the immune system . The treatment for lead poisoning consists of dimercaprol and succimer .

The concern about lead 's role in cognitive deficits in children has brought about widespread reduction in its use (lead exposure has been linked to learning disabilities) . Most cases of adult elevated blood lead levels are workplace @-@ related . High blood levels are associated with delayed puberty in girls . Lead has been shown many times to permanently reduce the cognitive capacity of children at extremely low levels of exposure .

Despite the toxicity of lead in significant amounts , there is some evidence that trace amounts of lead are beneficial in pigs and rats , and that its absence causes deficiency signs including depressed growth , anemia , and disturbed iron metabolism . If true in humans as well , this would make lead by far the heaviest essential element , since its atomic number (82) is much greater than that of the second @-@ heaviest such element , iodine (element 53) . Nevertheless , these findings are still uncertain , and even if lead does turn out to be beneficial in small quantities , the threshold of toxicity is so low that lead toxicity would remain a much higher priority to address than lead deficiency .

== Environmental ==

The extraction , production , use and disposal of lead and its products have caused significant contamination of the Earth 's soils and waters , posing a hazard to living organisms because of its toxicity . Atmospheric emissions of lead were at their peak during the Industrial Revolution and the period of leaded petrol in the second half of the twentieth century ; although these periods are over , elevated concentrations of lead persist in soils and sediments in post @-@ industrial and urban areas . Meanwhile , industrial emissions continue in many parts of the world .

=== Remediation ===

Fish bones are being researched for their ability to bioremediate lead in contaminated soil . The fungus *Aspergillus versicolor* is both greatly effective and fast at removing lead ions . Several bacteria have been researched for their ability to reduce lead ; including the sulfate reducing bacteria *Desulfovibrio* and *Desulfotomaculum* ; which are highly effective in aqueous solutions .

In the Netherlands , the use of lead shot for hunting and sport shooting was banned in 1993 , which caused a large drop in lead emission , from 230 tonnes in 1990 to 47 @. 5 tonnes in 1995 , two years after the ban .

== Restriction of lead usage ==

During the 20th century , the use of lead in paint pigments was sharply reduced because of the danger of lead poisoning , especially to children . By the mid @-@ 1980s , a significant shift in lead end @-@ use patterns had taken place . Much of this shift was a result of the U.S. lead consumers '

compliance with environmental regulations that significantly reduced or eliminated the use of lead in non @-@ battery products , including gasoline , paints , solders , and water systems . Lead use is being further curtailed by the European Union 's RoHS directive . Lead may still be found in harmful quantities in stoneware , vinyl (such as that used for tubing and the insulation of electrical cords) , and Chinese brass . Old houses may still contain substantial amounts of lead paint . White lead paint has been withdrawn from sale in industrialized countries , but the yellow lead chromate is still in use . Old paint should not be stripped by sanding , as this produces inhalable dust .

People can be exposed to lead in the workplace by breathing it in , swallowing it , skin contact , and eye contact . In the United States , the Occupational Safety and Health Administration (OSHA) has set the legal limit (permissible exposure limit) for lead exposure in the workplace as 0 @.@ 050 mg / m³ over an 8 @-@ hour workday , which applies to metallic lead , inorganic lead compounds , and lead soaps . The National Institute for Occupational Safety and Health (NIOSH) has set a recommended exposure limit (REL) of 0 @.@ 050 mg / m³ over an 8 @-@ hour workday , and recommends that workers ' blood concentrations of lead stay below 0 @.@ 060 mg per 100 g blood . At levels of 100 mg / m³ , lead is immediately dangerous to life and health .