Lead

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Lead (/lɛd/) is a chemical element with atomic number 82 and symbol **Pb** (from Latin: *plumbum*). It is a soft, malleable, and heavy 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's density of 11.34 g/cm^3 exceeds that of most common materials. Lead has the second highest atomic number of all practically stable elements. As such, lead is located at the end of some decay chains of heavier elements, which in part accounts for the relative abundance of lead: it exceeds those of other similarly-numbered elements.

Lead is a post-transition metal, and is relatively inert unless powdered. Its weakened metallic character is illustrated by its general amphoteric nature: it and its oxides react with both acids and bases. It also displays a marked tendency toward covalent bonding. Its compounds are most commonly found in the +2 oxidation state, rather than +4, unlike the lighter group 14 elements. Exceptions are mostly limited to organolead compounds, where the positive charge on lead is dispersed and stabilized. Like the lighter group 14 elements, lead shows a tendency to bond to itself, forming complicated chain, ring, or polyhedral structures.

Lead is relatively easy to extract, and the metal was known to prehistoric people in Western Asia. While its softness and dullness prevented it from high demand, galena—a principle ore of lead—often bore silver in it, which helped initiate production of lead. Lead production peaked in ancient Rome, and lead became easily available to common people. After the fall of Rome, levels of lead production fell, and those of Rome were not surpassed anywhere until as late as the Industrial Revolution. The metal was established as poisonous as late as in the late nineteenth century, which led to its eventual displacement from many uses, and it has been or is being phased out from those which include immediate contact to people.

Lead has several properties that make it advantageous to use, alongside its commonness: high density, low melting point, ductility, and relative inertness against oxygen attack. Lead minerals are easier to mine and lead is easier to extract from its ores than many other metals, which makes the resulting metal relatively inexpensive. For example, lead is used in building construction, lead–acid batteries, bullets and shot, weights, as part of solders, pewters, fusible alloys, and

Lead, $_{82}$Pb

General properties	
Name, symbol	lead, Pb
Appearance	metallic gray
Lead in the periodic table	
Atomic number (*Z*)	82
Group, block	group 14 (carbon group), p-block
Period	period 6
Element category	post-transition metal
Standard atomic weight (±) (A_r)	207.2(1)[1]
Electron configuration	[Xe] $4f^{14}$ $5d^{10}$ $6s^2$ $6p^2$
per shell	2, 8, 18, 32, 18, 4
Physical properties	
Phase	solid
Melting point	600.61 K (327.46 °C, 621.43 °F)
Boiling point	2022 K (1749 °C,

as a radiation shield. Currently, lead is produced in quantities of around ten thousand tonnes annually; secondary production from recycling is gaining ground, accounting for around half of that figure. Lead's toxicity has been a reason why lead was or is being phased out for some uses. If ingested or inhaled, lead and its compounds are poisonous to animals and humans. Lead is a neurotoxin which accumulates in soft tissues and bones, damaging the nervous system and causing brain disorders. Excessive lead also causes blood disorders in mammals.

Properties

Atomic

A lead atom has 82 electrons, arranged in an electronic configuration of $[Xe]4f^{14}5d^{10}6s^{2}6p^{2}$. The combined first and second ionization energy of lead—the total energy required to remove the two 6p electrons from a neutral lead atom—is close to that of tin, its upper neighbor in group 14. This is unusual since ionization energies generally fall going down a group as an element's electrons become more distant from its nucleus. The similarity is attributable to the lanthanide contraction. This describes the greater-than-expected decrease in the radii of elements in the lanthanide series from atomic number 57, lanthanum, to 71, lutetium, and causes smaller than otherwise expected ionic radii for the subsequent elements starting with 72, hafnium. It results from poor shielding of the nucleus by the lanthanide 4f electrons; the outer electrons are drawn towards the nucleus, thus resulting in a smaller atomic radius. The combined first four ionization energies of lead exceed those of tin[7] contrary to what the periodic trends would predict. For this reason lead, unlike tin,[8] rarely has a +4 oxidation state in inorganic compounds.[8] Such behavior is attributable to relativistic effects, which become particularly prominent at the bottom of the periodic table;[8] the result is that the 6s electrons of lead become reluctant to participate in bonding,[a] a phenomenon referred to as the inert pair effect.

All the lighter elements in group 14 have a stable or metastable allotrope in which they crystallize in the diamond cubic structure, involving covalent bonds. In this structure, each atom is tetrahedrally coordinated, indicating that all four bonds are equivalent, having each attained the lowest possible energy. To explain this, in spite

	3180 °F)
Density near r.t.	11.34 g/cm^3
when liquid, at m.p.	10.66 g/cm^3
Heat of fusion	4.77 kJ/mol
Heat of vaporization	179.5 kJ/mol
Molar heat capacity	26.650 J/(mol·K)

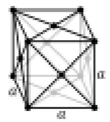
Vapor pressure

P (Pa)	**1**	**10**	**100**	**1 k**	**10 k**	**100 k**
at T (K)	978	1088	1229	1412	1660	2027

Atomic properties

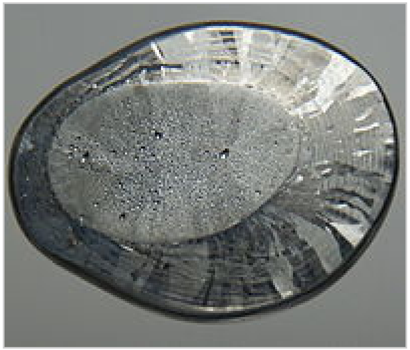
Oxidation states	**4**, 3, **2**, 1, −1, −2, −4 (an amphoteric oxide)
Electronegativity	Pauling scale: 1.87
Ionization energies	1st: 715.6 kJ/mol 2nd: 1450.5 kJ/mol 3rd: 3081.5 kJ/mol
Atomic radius	empirical: 175 pm
Covalent radius	146±5 pm
Van der Waals radius	202 pm

Miscellanea

Crystal structure	face-centered cubic (fcc) 
Speed of sound thin rod	1190 m/s (at r.t.) (annealed)
Thermal expansion	28.9 µm/(m·K) (at 25 °C)
Thermal	35.3 W/(m·K)

of the fact that two of the electrons are in s-orbitals and the other two in higher-energy p-orbitals, orbital hybridization is invoked, in which one of the electrons is "promoted" from an s-orbital to a p-orbital, and then all form four intermediate hybrid orbitals in a process called sp^3 hybridization. The inert pair effect affects the crystal structure of lead, because the promotion energy of a 6s-electron becomes larger than the amount of energy that would be released from the additional bonds formed.[10] Thus, rather than having the diamond-cubic covalent structure, lead forms metallic bonds, in which only the p-electrons are delocalized and shared between the Pb^{2+} ions, resulting in a face-centered cubic structure like those of the similarly-sized divalent calcium and strontium.[11]

Physical


A sample of lead freshly solidified from molten state

Lead is a bright silvery metal with a very slight shade of blue in a dry atmosphere.[12] It tarnishes on contact with moist air, forming a complex surface mixture of compounds whose color and composition will vary depending on the prevailing conditions. Lead's characteristic properties include high density, softness, malleability, ductility, poor electrical conductivity compared to other metals, high resistance to corrosion (conferred by its surface patina), and a propensity to react with organic reagents.[12]

Lead's face-centered cubic structure and high atomic weight give it a characteristically high density[13] of 11.34 g/cm^3, hence the idiom *go down like a lead balloon*.[14] Its density exceeds that of common metals such as iron (7.87 g/cm^3), copper (8.93 g/cm^3), zinc (7.14 g/cm^3).[15] Some rarer metals are denser: tungsten and gold are both 19.3 g/cm^3, while the densest metal known—osmium—has a density of 22.59 g/cm^3, almost twice that of lead.[16]

Lead is a very soft material with a Mohs hardness of 1.5; it can be scratched with a fingernail.[17] It is malleable and ductile[b] metal, with its malleability exceeding its ductility.[18] Lead easily changes its shape, compared to most metals.[19] Its compressive strength is high and it can therefore be rolled into extremely thin sheets.[18] The bulk modulus—a measure of the ease of

conductivity	
Electrical resistivity	208 nΩ·m (at 20 °C)
Magnetic ordering	diamagnetic
Young's modulus	16 GPa
Shear modulus	5.6 GPa
Bulk modulus	46 GPa
Poisson ratio	0.44
Mohs hardness	1.5
Brinell hardness	38–50 MPa
CAS Number	7439-92-1

History

Discovery	Middle Easterns (7000 BCE)

Most stable isotopes of lead

iso	NA	half-life	DM	DE (MeV)	DP
^{202}**Pb**	syn	53000 y	ε	0.0497	^{202}Tl
^{204}**Pb**	1.4%	is stable with 122 neutrons			
^{205}**Pb**	trace	1.53×10^7 y	ε	0.051	^{205}Tl
^{206}**Pb**	24.1%	is stable with 124 neutrons			
^{207}**Pb**	22.1%	is stable with 125 neutrons			
^{208}**Pb**	52.4%	is stable with 126 neutrons			
^{210}**Pb**	trace	22.3 y	β^-	0.064	^{210}Bi

compressibility of a material—of lead is 45.8 GPa. (For comparison, that of aluminium is 75.2 GPa; copper 137.8 GPa; and mild steel 160–169 GPa.)[20] Lead has to be treated carefully when being elongated into wire as its tensile strength is comparatively low: 12–17 MPa (that of aluminium is 6 times higher; copper 10 times higher; mild steel 15 times higher); this value is easily improved by adding small concentrations of other metals (such as antimony or copper).[19]

The melting point of lead is 327.5 °C (621.5 °F),[21] which is considered low from an industrial perspective.[22][c] Its boiling point is 1749 °C (3180 °F).[24] The electrical resistivity of lead at 20 °C is 208 nano-ohm-meters; this almost an order of magnitude higher than those of industrially applied metals (that of copper is 17.12 nΩ·m; gold 22.55 nΩ·m; aluminium 27.09 nΩ·m). Lead is a superconductor at temperatures lower than 7.19 K;[25] this critical temperature is the highest of all type-I superconductors and the third highest of all elemental superconductors.

Chemical

As with many metals, finely divided powdered lead exhibits pyrophoricity.[26] It burns with a bluish-white flame.

Bulk lead exposed to moist air forms a protective layer of varying composition. A common reaction is the formation of the oxide which in turn reacts with carbon dioxide to give lead carbonate.[27][28][29] Other insoluble compounds, such the sulfate or chloride, may form the protective layer if lead is exposed to a different chemical environment.[30]

Fluorine reacts with lead at room temperature, forming lead(II) fluoride. The reaction with chlorine is similar, but requires heating: the chloride layer diminishes the reactivity of the elements.[31][30] Molten lead reacts with the chalcogens to give lead(II) chalcogenides.[32]

The 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 this gas will result in the formation of the soluble bicarbonate, which makes the use of lead pipes dangerous.[33] Water in the presence of oxygen attacks lead to start an accelerating reaction.[34] Lead also dissolves in concentrated alkalis (≥10%) because of the amphoteric character and solubility of plumbites.[33]

The metal is not attacked by dilute sulfuric acid; the concentrated acid dissolves lead thanks to complexation.[34] Lead reacts slowly with hydrochloric acid; nitric acid reacts vigorously to form nitrogen oxides and lead(II) nitrate.[34] Organic acids, such as acetic acid, also dissolve lead, but this reaction requires oxygen as well.[30]

Isotopes

Lead has four stable isotopes, lead-204, lead-206, lead-207, and lead-208.[35] The high number of stable isotopes relies on the fact that lead's atomic number of 82 is even, and is a magic number.[d] With its high atomic number, lead is the second-heaviest element that occurs naturally in the form of isotopes regarded as stable: bismuth has a higher atomic number of 83, but its only primordial isotope was found in 2003 to be very slightly radioactive.[e] The four stable isotopes of lead could theoretically undergo alpha decay to isotopes of mercury with a release of energy, but this has not been observed for any of them:[36] accordingly, their predicted half-lives are extremely long, ranging up to over 10^{100} years.[39][f] As such, lead is often quoted as the heaviest stable element.

Flame test: lead colors flame pale blue

Holsinger meteorite, the largest piece of the Canyon Diablo meteorite. Uranium–lead dating and lead–lead dating on this meteorite allowed refinement of the age of the Earth to 4.55 billion ± 70 million years.

Three of these isotopes are 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. Since the amounts of them in nature depend 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 20.84% and 27.78%,[35] and the abundance of lead-208 may vary between 52.4% in normal samples to 90% in thorium ores.[40] (For this reason, the atomic weight of lead is given to only one decimal place.[41]) As time passes, the ratio of lead-206 and lead-207 to 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.[42]

Apart from the stable isotopes, which make up almost all 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,[36] a period too short to allow any primordial lead-210 to 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, it is 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 useful 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).[43][44] 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.[45]

In total, thirty-eight isotopes of lead have been synthesized, with mass numbers of 178–215.[36] Lead-205 is the most stable radioisotope of lead, with a half-life of around 1.5×10^7 years.[g] 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), of 24 lead isotopes, have been characterized. The longest-lived isomer is lead-204m2 with a half-life of about 1.1 hours).[36]

External links

- Wikipedia: Lead (https://en.wikipedia.org/wiki/Lead_(element))