Aluminium

From Wikipedia, the free encyclopedia
(Redirected from Aluminum)

Aluminium (/ˌæljuːˈmɪniəm/ ***AL-ew-MIN-ee-əm***) or **aluminum** (American English; /əlˈuːmɪnəm/ ***ə-LOO-mi-nəm***) is a silvery white member of the boron group of chemical elements. It has the symbol **Al**, and its atomic number is 13. It is not soluble in water under normal circumstances.

Aluminium is the third most abundant element (after oxygen and silicon), and the most abundant metal, in the Earth's crust. It makes up about 8% by weight of the Earth's solid surface. Aluminium metal is too reactive chemically to occur natively. Instead, it is found combined in over 270 different minerals.[4] The chief ore of aluminium is bauxite.

Aluminium is remarkable for the metal's low density and for its ability to resist corrosion due to the phenomenon of passivation. Structural components made from aluminium and its alloys are vital to the aerospace industry and are important in other areas of transportation and structural materials. The most useful compounds of aluminium, at least on a weight basis, are the oxides and sulfates.

Despite its prevalence in the environment, aluminium salts are not known to be used by any form of life. In keeping with its pervasiveness, aluminium is well tolerated by plants and animals.[5] Due to their prevalence, potential beneficial (or otherwise) biological roles of aluminium compounds are of continuing interest.

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magnesium ← **aluminium** → silicon

B
↑
Al
↓
Ga

13Al□

Periodic table

Appearance

silvery gray metallic

Spectral lines of aluminium

General properties	
Name, symbol, number	aluminium, Al, 13
Pronunciation	UK /ˌæljʉˈmɪniəm/ ***AL-ew-MIN-ee-əm***; or US /əˈluːmɪnəm/ ***ə-LOO-mi-nəm***
Element category	other metal
Group, period, block	13, 3, p
Standard atomic weight	26.981 5386(13)
Electron configuration	[Ne] $3s^2$ $3p^1$

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Characteristics

Etched surface from a high purity (99.9998%) aluminium bar, size 55×37 mm

Physical

Aluminium is a relatively soft, durable, lightweight, ductile and malleable metal with appearance ranging from silvery to dull gray, depending on the surface roughness. It is nonmagnetic and does not easily ignite. A fresh film of aluminium

Electrons per shell	2, 8, 3 (Image)
Physical properties	
Phase	solid
Density (near r.t.)	2.70 g·cm^{-3}
Liquid density at m.p.	2.375 g·cm^{-3}
Melting point	933.47 K, 660.32 °C, 1220.58 °F
Boiling point	2792 K, 2519 °C, 4566 °F
Heat of fusion	10.71 kJ·mol^{-1}
Heat of vaporization	294.0 kJ·mol^{-1}
Molar heat capacity	24.200 J·mol^{-1}·K^{-1}

Vapor pressure

P (Pa)	1	10	100	1 k	10 k	100 k
at T (K)	1482	1632	1817	2054	2364	2790

Atomic properties	
Oxidation states	**3**, 2[1], 1[2] (amphoteric oxide)
Electronegativity	1.61 (Pauling scale)
Ionization energies (more)	1st: 577.5 kJ·mol^{-1} 2nd: 1816.7 kJ·mol^{-1} 3rd: 2744.8 kJ·mol^{-1}
Atomic radius	143 pm
Covalent radius	121 ±4 pm
Van der Waals radius	184 pm
Miscellanea	
Crystal structure	face-centered cubic
Magnetic ordering	paramagnetic[3]
Electrical resistivity	(20 °C) 28.2 nΩ·m
Thermal conductivity	237 W·m^{-1}·K^{-1}
Thermal expansion	(25 °C) 23.1 µm·m^{-1}·K^{-1}
Speed of sound (thin rod)	(r.t.) (rolled) 5,000 m·s^{-1}
Young's modulus	70 GPa
Shear modulus	26 GPa

film serves as a good reflector (approximately 92%) of visible light and an excellent reflector (as much as 98%) of medium and far infrared radiation. The yield strength of pure aluminium is 7–11 MPa, while aluminium alloys have yield strengths ranging from 200 MPa to 600 MPa.[6] Aluminium has about one-third the density and stiffness of steel. It is easily machined, cast, drawn and extruded.

Aluminium atoms are arranged in a face-centered cubic (fcc) structure. Aluminium has a stacking-fault energy of approximately 200 mJ/m^2.[7]

Aluminium is a good thermal and electrical conductor, having 59% the conductivity of copper, both thermal and electrical. Aluminium is capable of being a superconductor, with a superconducting critical temperature of 1.2 Kelvin and a critical magnetic field of about 100 gauss (10 milliteslas).[8]

Bulk modulus	76 GPa
Poisson ratio	0.35
Mohs hardness	2.75
Vickers hardness	167 MPa
Brinell hardness	245 MPa
CAS registry number	7429-90-5

Most stable isotopes

Main article: Isotopes of aluminium

iso	NA	half-life	DM	DE (MeV)	DP
^{26}Al	trace	7.17×10^5 a	β^+	1.17	^{26}Mg
			ε	-	^{26}Mg
			γ	1.8086	-
^{27}Al	100%	^{27}Al is stable with 14 neutrons			

Chemical

Corrosion resistance can be excellent due to a thin surface layer of aluminium oxide that forms when the metal is exposed to air, effectively preventing further oxidation. The strongest aluminium alloys are less corrosion resistant due to galvanic reactions with alloyed copper.[6] This corrosion resistance is also often greatly reduced by aqueous salts, particularly in the presence of dissimilar metals.

Owing to its resistance to corrosion, aluminium is one of the few metals that retain silvery reflectance in finely powdered form, making it an important component of silver-colored paints. Aluminium mirror finish has the highest reflectance of any metal in the 200–400 nm (UV) and the 3,000–10,000 nm (far IR) regions; in the 400–700 nm visible range it is slightly outperformed by tin and silver and in the 700–3000 (near IR) by silver, gold, and copper.[9]

Aluminium is oxidized by water to produce hydrogen and heat:

$$2\ Al + 3\ H_2O \rightarrow Al_2O_3 + 3H_2$$

This conversion is of interest for the production. Challenges include circumventing the formed oxide layer which inhibits the reaction and the expenses associated with the storage of energy by regeneration of the Al metal.[10]

Isotopes

Main article: Isotopes of aluminium

Aluminium has many known isotopes, whose mass numbers range from 21 to 43; however, only ^{27}Al (stable isotope) and ^{26}Al (radioactive isotope, $t_{1/2} = 7.2\times10^5$ y) occur naturally. ^{27}Al has a natural abundance above 99.9%. ^{26}Al is produced from argon in the atmosphere by spallation caused by cosmic-ray protons. Aluminium isotopes have found practical application in dating marine sediments, manganese nodules, glacial ice, quartz in rock exposures, and meteorites. The ratio of ^{26}Al to ^{10}Be has been used to study the role of transport, deposition, sediment storage, burial times, and erosion on 10^5 to 10^6 year time scales.[11] Cosmogenic ^{26}Al was first applied in studies of the Moon and meteorites. Meteoroid fragments, after departure from their parent bodies, are exposed to intense cosmic-ray bombardment during their travel through space, causing substantial ^{26}Al production. After falling to Earth, atmospheric shielding drastically reduces ^{26}Al production, and its decay can then be used to determine the meteorite's terrestrial age. Meteorite research has also shown that ^{26}Al was relatively abundant at the time of formation of our planetary system. Most meteorite scientists believe that the energy released by the decay of ^{26}Al was responsible for the melting and differentiation of some asteroids after their formation 4.55 billion years ago.[12]

Natural occurrence

See also: List of countries by bauxite production

Stable aluminium is created when hydrogen fuses with magnesium either in large stars or in supernovae.[13]

In the Earth's crust, aluminium is the most abundant (8.3% by weight) metallic element and the third most abundant of all elements (after oxygen and silicon).[14] Because of its strong affinity to oxygen, it is almost never found in the elemental state; instead it is found in oxides or silicates. Feldspars, the most common group of minerals in the Earth's crust, are aluminosilicates. Native aluminium metal can only be found as a minor phase in low oxygen fugacity environments, such as the interiors of certain volcanoes.[15] Native aluminium has been reported in cold seeps in the northeastern continental slope of the South China Sea and Chen et al. (2011)[16] have proposed a theory of its origin as resulting by reduction from tetrahydroxoaluminate $Al(OH)_4^-$ to metallic aluminium by bacteria.[16]

It also occurs in the minerals beryl, cryolite, garnet, spinel and turquoise. Impurities in Al_2O_3, such as chromium or iron yield the gemstones ruby and sapphire, respectively.

Although aluminium is an extremely common and widespread element, the common aluminium minerals are not economic sources of the metal. Almost all metallic aluminium is produced from the ore bauxite ($AlO_x(OH)_{3-2x}$). Bauxite occurs as a weathering product of low iron and silica bedrock in tropical climatic conditions.[17] Large deposits of bauxite occur in Australia, Brazil, Guinea and Jamaica and the primary mining areas for the ore are in Australia, Brazil, China, India, Guinea, Indonesia, Jamaica, Russia and Suriname.

Production and refinement

See also: Category:Aluminium minerals and List of countries by aluminium production

Bauxite, a major aluminium ore. The red-brown colour is due to the presence of iron minerals.

Aluminium forms strong chemical bonds with oxygen. Compared to most other metals, it is difficult to extract from ore, such as bauxite, due to the high reactivity of aluminum and the high melting point of most of its ores. For example, direct reduction with carbon, as is used to produce iron, is not chemically possible because aluminium is a stronger reducing agent than carbon. Indirect carbothermic reduction can be carried out using carbon and Al_2O_3, which forms an intermediate Al_4C_3 and this can further yield aluminium metal at a temperature of 1900–2000 °C. This process is still under development; it requires less energy and yields less CO_2 than the Hall-Héroult process, the major industrial process for aluminium extraction.[18] Electrolytic smelting of alumina was originally cost-prohibitive in part because of the high melting point of alumina, or aluminium oxide, (about 2,000 °C (3,600 °F)). Many minerals, however, will dissolve into a second already molten mineral, even if the temperature of the melt is significantly lower than the melting point of the first mineral. Molten cryolite was discovered to dissolve alumina at temperatures signifcanlty lower than the melting point of pure alumina without interfering in the smelting process. In the Hall-Héroult process, alumina is first dissolved into molten cryolite with calcium fluoride and then electolytically reduced to aluminium at a temperature between 950 and 980 °C (1,740 to 1,800 °F). Cryolite is a chemical compound of aluminium and sodium fluorides: (Na_3AlF_6). Although cryolite is found as a mineral in Greenland, its synthetic form is used in the industry. The aluminium oxide itself is obtained by refining bauxite in the Bayer process.

The electrolytic process replaced the Wöhler process, which involved the reduction of anhydrous aluminium chloride with potassium. Both of the electrodes used in the electrolysis of aluminium oxide are carbon. Once the refined alumina is dissolved in the electrolyte, it disassociates and its ions are free to move around. The reaction at the cathode is:

$$Al^{3+} + 3\ e^- \rightarrow Al$$

Here the aluminium ion is being reduced. The aluminium metal then sinks to the bottom and is tapped off, usually cast into large blocks called aluminium billets for further processing.

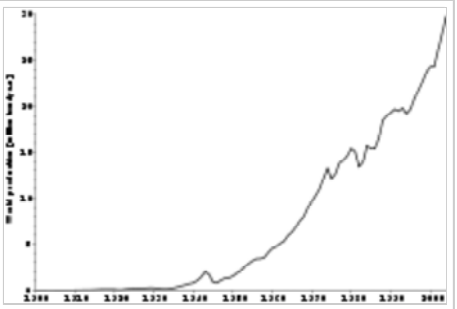
At the anode, oxygen is formed:

$$2\ O^{2-} \rightarrow O_2 + 4\ e^-$$

To some extent, the carbon anode is consumed by subsequent reaction with oxygen to form carbon dioxide. The anodes in a reduction cell must therefore be replaced regularly, since they are consumed in the process. The cathodes do erode, mainly due to electrochemical processes and metal movement. After five to ten years, depending on the current used in the electrolysis, a cell has to be rebuilt because of cathode wear.

Aluminium electrolysis with the Hall-Héroult process consumes a lot of energy, but alternative processes were always found to be less viable economically and/or ecologically. The worldwide average specific energy consumption is approximately 15±0.5

kilowatt-hours per kilogram of aluminium produced (52 to 56 MJ/kg). The most modern smelters achieve approximately 12.8 kW·h/kg (46.1 MJ/kg). (Compare this to the heat of reaction, 31 MJ/kg, and the Gibbs free energy of reaction, 29 MJ/kg.) Reduction line currents for older technologies are typically 100 to 200 kiloamperes; state-of-the-art smelters operate at about 350 kA. Trials have been reported with 500 kA cells.[*citation needed*]


World production trend of aluminium

The Hall-Heroult process produces aluminium with a purity of above 99%. Further purification can be done by the Hoope process. The process involves the electrolysis of molten aluminium with a sodium, barium and aluminium fluoride electrolyte. The resulting aluminium has a purity of 99.99%.[19][20]

Electric power represents about 20% to 40% of the cost of producing aluminium, depending on the location of the smelter. Aluminium production consumes roughly 5% of electricity generated in the U.S.[21] Smelters tend to be situated where electric power is both plentiful and inexpensive, such as the United Arab Emirates with excess natural gas supplies and Iceland and Norway with energy generated from renewable sources. The world's largest smelters of alumina are People's Republic of China, Russia, and Quebec and British Columbia in Canada.[21][22][23]

In 2005, the People's Republic of China was the top producer of aluminium with almost a one-fifth world share, followed by Russia, Canada, and the USA, reports the British Geological Survey.

Aluminium output in 2005

Over the last 50 years, Australia has become a major producer of bauxite ore and a major producer and exporter of alumina (before being overtaken by China in 2007).[22][24] Australia produced 62 million tonnes of bauxite in 2005. The Australian deposits have some refining problems, some being high in silica, but have the advantage of being shallow and relatively easy to mine.[25]

Recycling

Main article: Aluminium recycling

Aluminium is theoretically 100% recyclable without any loss of its natural qualities. According to the International Resource Panel's Metal Stocks in Society report, the global per capita stock of aluminium in use in society (i.e. in cars, buildings, electronics etc.) is 80 kg. Much of this is in more-developed countries (350–500 kg per capita) rather than less-developed countries (35 kg per capita). Knowing the per capita stocks and their approximate lifespans is important for planning recycling.

Aluminium recycling code

Recovery of the metal via recycling has become an important facet of the aluminium industry. Recycling was a low-profile activity until the late 1960s, when the growing use of aluminium beverage cans brought it to the public awareness.

Recycling involves melting the scrap, a process that requires only 5% of the energy used to produce aluminium from ore, though a significant part (up to 15% of the input material) is lost as dross (ash-like oxide).[26] The dross can undergo a further process to extract aluminium.

In Europe aluminium experiences high rates of recycling, ranging from 42% of beverage cans, 85% of construction materials and 95% of transport vehicles.[27]

Recycled aluminium is known as secondary aluminium, but maintains the same physical properties as primary aluminium. Secondary aluminium is produced in a wide range of formats and is employed in 80% of alloy injections. Another important use is for extrusion.

White dross from primary aluminium production and from secondary recycling operations still contains useful quantities of aluminium that can be extracted industrially.[28] The process produces aluminium billets, together with a highly complex waste material. This waste is difficult to manage. It reacts with water, releasing a mixture of gases (including, among others, hydrogen, acetylene, and ammonia), which spontaneously ignites on contact with air;[29] contact with damp air results in the release of copious quantities of ammonia gas. Despite these difficulties, the waste has found use as a filler in asphalt and concrete.[30]

Compounds

Oxidation state +3

The vast majority of compounds, including all Al-containing minerals and all commercially significant aluminium compounds, feature aluminium in the oxidation state 3+. The coordination number of such compounds varies, but generally Al^{3+} is six-coordinate or tetracoordinate. Almost all compounds of aluminium(III) are colorless.[14]

Halides

All four trihalides are well known. Unlike the structures of the three heavier trihalides, aluminium fluoride (AlF_3) features six-coordinate Al. The octahedral coordination environment for AlF_3 is related to the compactness of fluoride ion, six of which can fit around the small Al^{3+} centre. AlF_3 sublimes (with cracking) at 1,291 °C (2,356 °F). With heavier halides, the coordination numbers are lower. The other trihalides are dimeric or polymeric with tetrahedral Al centers. These materials are prepared by treating aluminium metal with the halogen, although other methods exist. Acidification of the oxides or hydroxides affords hydrates. In aqueous solution, the halides often form mixtures, generally containing six-coordinate Al centres, which are feature both halide and aquo ligands. When aluminium and fluoride are together in aqueous solution, they readily form complex ions such as $[AlF(H_2O)_5]^{2+}$, $AlF_3(H_2O)_3$, and $[AlF_6]^{3-}$. In the case of chloride, polyaluminium clusters are formed such as $[Al_{13}O_4(OH)_{24}(H_2O)_{12}]^{7+}$.

Oxide and hydroxides

Aluminium forms one stable oxide, known by its mineral name corundum. Sapphire and ruby are impure corundum contaminated with trace amounts of other metals. The two oxide-hydroxides (AlO(OH) are boehmite and diaspore. There are three trihydroxides: bayerite, gibbsite, and nordstrandite, which differ in their crystalline structure (polymorphs). Most are produced from ores by a variety of wet processes using acid and base. Heating the hydroxides leads to formation of corundrum. These materials are of central importance to the production of aluminium and are themselves extremely useful.

Carbide, nitride, and related materials

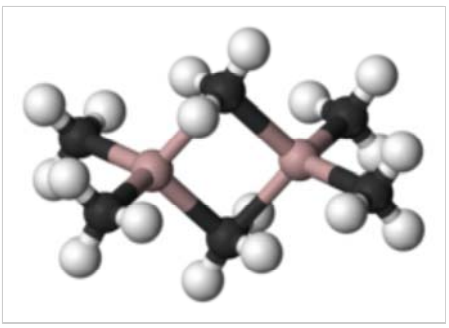
Aluminium carbide (Al_4C_3) is made by heating a mixture of the elements above 1,000 °C (1,832 °F). The pale yellow crystals consist of tetrahedral aluminium centres. It reacts with water or dilute acids to give methane. The acetylide, $Al_2(C_2)_3$, is made by passing acetylene over heated aluminium.

Aluminium nitride (AlN) is the only nitride known for aluminium. Unlike the oxides it features tetrahedral Al centres. It can be made from the elements at 800 °C (1,472 °F). It is air-stable material with a usefully high thermal conductivity. Aluminium phosphide (AlP) is made similarly, and hydrolyses to give phosphine:

$$AlP + 3\ H_2O \rightarrow Al(OH)_3 + PH_3$$

Organoaluminium compounds and related hydrides

Main article: Organoaluminium compound



Structure of trimethylaluminium, a compound that features five-coordinate carbon.

A variety of compounds of empirical formula AlR_3 and $AlR_{1.5}Cl_{1.5}$ exist.[31] These species usually feature tetrahedral Al centres, e.g. "trimethylaluminium" has the formula $Al_2(CH_3)_6$ (see figure). With large organic groups, triorganoaluminium exist as three-coordinate monomers, such as triisobutylaluminium. Such compounds are widely used in industrial chemistry, despite the fact that they are often highly pyrophoric. Few analogues exist between organoaluminium and organoboron compounds except for large organic groups.

The important aluminium hydride is lithium aluminium hydride ($LiAlH_4$), which is used in as a reducing agent in organic chemistry. It can be produced from lithium hydride and aluminium trichloride:

$$4\ LiH + AlCl_3 \rightarrow LiAlH_4 + 3\ LiCl$$

Several useful derivatives of $LiAlH_4$ are known, e.g. Sodium bis(2-methoxyethoxy)dihydridoaluminate. The simplest hydride, aluminium hydride or alane, remains a laboratory curiosity. It is a polymer with the formula $(AlH_3)_n$, in contrast to the corresponding boron hydride with the formula $(BH_3)_2$.

Oxidation states +1 and +2

Although the great majority of aluminium compounds feature Al^{3+} centres, compounds with lower oxidation states are known and sometime of significance as precursors to the Al^{3+} species.

Aluminium(I)

AlF, AlCl and AlBr exist in the gaseous phase when the tri-halide is heated with aluminium. The composition AlI is unstable at room temperature with respect to the triiodide:[32]

$$3\ AlI \rightarrow AlI_3 + 2\ Al$$

A stable derivative of aluminium monoiodide is the cyclic adduct formed with triethylamine, $Al_4I_4(NEt_3)_4$. Also of theoretical interest but only of fleeting existence are Al_2O and Al_2S is made by heating the normal oxide, Al_2O_3, with silicon at 1,800 °C (3,272 °F) in a vacuum.[32] Such materials quickly disproportionates to the starting materials.

Aluminium(II)

Very simple Al(II) compounds are invoked or observed in the reactions of Al metal with oxidants. For example, aluminium monoxide, AlO, has been detected in the gas phase after explosion[33] and in stellar absorption spectra.[34] More thoroughly investigated are compounds of the formula R_4Al_2 where R is a large organic ligand.[35]

Analysis

The presence of aluminium can be detected in qualitative analysis using aluminon.

Applications

General use

Aluminium is the most widely used non-ferrous metal.[36] Global production of aluminium in 2005 was 31.9 million tonnes. It exceeded that of any other metal except iron (837.5 million tonnes).[37] Forecast for 2012 is 42–45 million tonnes, driven by rising Chinese output.[38]

Aluminium is almost always alloyed, which markedly improves its mechanical properties, especially when tempered. For example, the common aluminium foils and beverage cans are alloys of 92% to 99% aluminium.[39] The main alloying agents are copper, zinc, magnesium, manganese, and silicon (e.g., duralumin) and the levels of these other metals are in the range of a few percent by weight.[40]

Some of the many uses for aluminium metal are in:

- Transportation (automobiles, aircraft, trucks, railway cars, marine vessels, bicycles, etc.) as sheet, tube, castings, etc.

- Packaging (cans, foil, etc.)
- Construction (windows, doors, siding, building wire, etc.).[41]
- A wide range of household items, from cooking utensils to baseball bats, watches.[42]
- Street lighting poles, sailing ship masts, walking poles, etc.
- Outer shells of consumer electronics, also cases for equipment e.g. photographic equipment.
- Electrical transmission lines for power distribution
- MKM steel and Alnico magnets
- Super purity aluminium (SPA, 99.980% to 99.999% Al), used in electronics and CDs.
- Heat sinks for electronic appliances such as transistors and CPUs.
- Substrate material of metal-core copper clad laminates used in high brightness LED lighting.
- Powdered aluminium is used in paint, and in pyrotechnics such as solid rocket fuels and thermite.
- Aluminium can be reacted with hydrochloric acid or with sodium hydroxide to produce hydrogen gas.
- A variety of countries, including France, Italy, Poland, Finland, Romania, Israel, and the former Yugoslavia, have issued coins struck in aluminium or aluminium-copper alloys.[43][44]
- Some guitar models sports aluminium diamond plates on the surface of the instruments, usually either chrome or black. Kramer Guitars and Travis Bean are both known for having produced guitars with necks made of aluminium, which gives the instrument a very distinct sound.

Household aluminium foil

Aluminium-bodied Austin *"A40 Sports"* (circa 1951)

Aluminium slabs being transported from a smelter

Aluminium is usually alloyed – it is used as pure metal only when corrosion resistance and/or workability is more important than strength or hardness. A thin layer of aluminium can be deposited onto a flat surface by physical vapour deposition or (very infrequently) chemical vapour deposition or other chemical means to form optical coatings and mirrors.

Aluminium compounds

Because aluminium is abundant and most of its derivative exhibit low toxicity, the compounds of aluminium enjoy wide and sometimes large-scale applications.

Alumina

Main article: Aluminium oxide

Aluminium oxide (Al_2O_3) and the associated oxy-hydroxides and trihydroxides are produced or extracted from minerals on a large scale. The great majority of this material is converted to metallic aluminium. About 10% of the production capacity is used for other applications. A major use is as an absorbent, for example alumina will remove water from hydrocarbons, to enable subsequent processes that are poisoned by moisture. Aluminium oxides are common catalysts for industrial processes, e.g. the Claus process for converting hydrogen sulfide to sulfur in refineries and for the alkylation of amines. Many industrial catalysts are "supported", meaning generally that an expensive catalyst (e.g., platinum) is dispersed over a high surface area material such as alumina. Being a very hard material (Mohs hardness 9), alumina is widely used as an abrasive and the production of applications that exploit its inertness, e.g., in high pressure sodium lamps.

Sulfates

Several sulfates of aluminium find applications. Aluminium sulfate ($Al_2(SO_4)_3(H_2O)_{18}$) is produced on the annual scale of several billions of kilograms. About half of the production is consumed in water treatment. The next major application is in the manufacture of paper. It is also used as a mordant, in fire extinguisher, as a food additive, in fireproofing, and in leather tanning. Aluminium ammonium sulfate, which is also called ammonium alum, $(NH_4)Al(SO_4)_2 \cdot 12H_2O$, is used as a mordant and in leather tanning.[5] Aluminium potassium sulfate ($[Al(K)](SO_4)_2)(H_2O)_{12}$ is used similarly. The consumption of both alums is declining.

Chlorides

Aluminium chloride ($AlCl_3$) is used in petroleum refining and in the production of synthetic rubber and polymers. Although it has a similar name, aluminium chlorohydrate has fewer and very different applications, e.g. as a hardening agent and an antiperspirant. It is an intermediate in the production of aluminium metal.

Niche compounds

Given the scale of aluminium compounds, a small scale application could still involve thousands of tonnes. One of the many compounds used at this intermediate level include aluminium acetate, a salt used in solution as an astringent. Aluminium borate ($Al_2O_3 \cdot B_2O_3$) is used in the production of glass and ceramics. Aluminium fluorosilicate ($Al_2(SiF_6)_3$) is used in the production of synthetic gemstones, glass and ceramic. Aluminium phosphate ($AlPO_4$) is used in the manufacture: of glass and ceramic, pulp and paper products, cosmetics, paints and varnishes and in making dental cement. Aluminium hydroxide ($Al(OH)_3$) is used as an antacid, as a mordant, in water purification, in the manufacture of glass and ceramic and in the waterproofing of fabrics. Lithium aluminium hydride is a powerful reducing agent used in organic chemistry. Organoaluminiums are used as Lewis acids and cocatalysts. For example, methylaluminoxane is a cocatalyst for Ziegler-Natta olefin polymerization to produce vinyl polymers such as polyethene.

Aluminium alloys in structural applications

Main article: Aluminium alloy

Aluminium alloys with a wide range of properties are used in engineering structures. Alloy systems are classified by a number system (ANSI) or by names indicating their main alloying constituents (DIN and ISO).

The strength and durability of aluminium alloys vary widely, not only as a result of the components of the specific alloy, but also as a result of heat treatments and manufacturing processes. A lack of knowledge of these aspects has from time to time led to improperly designed structures and gained aluminium a bad reputation.

One important structural limitation of aluminium alloys is their fatigue strength. Unlike steels, aluminium alloys have no well-defined fatigue limit, meaning that fatigue failure eventually occurs, under even very small cyclic loadings. This implies that engineers must assess these loads and design for a fixed life rather than an infinite life.

Aluminium foam

Another important property of aluminium alloys is their sensitivity to heat. Workshop procedures involving heating are complicated by the fact that aluminium, unlike steel, melts without first glowing red. Forming operations where a blow torch is used therefore require some expertise, since no visual signs reveal how close the material is to melting. Aluminium alloys, like all structural alloys, also are subject to internal stresses following heating operations such as welding and casting. The problem with aluminium alloys in this regard is their low melting point, which make them more susceptible to distortions from thermally induced stress relief. Controlled stress relief can be done during manufacturing by heat-treating the parts in an oven, followed by gradual cooling—in effect annealing the stresses.

The low melting point of aluminium alloys has not precluded their use in rocketry; even for use in constructing combustion chambers where gases can reach 3500 K. The Agena upper stage engine used a regeneratively cooled aluminium design for some parts of the nozzle, including the thermally critical throat region.

Another alloy of some value is aluminium bronze (Cu-Al alloy).

History

Ancient Greeks and Romans used aluminium salts as dyeing mordants and as astringents for dressing wounds; alum is still used as a styptic. In 1761, Guyton de Morveau suggested calling the base alum *alumine.* In 1808, Humphry Davy identified the existence of a metal base of alum, which he at first termed *alumium* and later *aluminum* (see etymology section, below).

The statue of the Anteros (commonly mistaken for either *The Angel of Christian Charity* or *Eros*) in Piccadilly Circus, London, was made in 1893 and is one of the first statues to be cast in aluminium.

The metal was first produced in 1825 in an impure form by Danish physicist and chemist Hans Christian Ørsted. He reacted anhydrous aluminium chloride with potassium amalgam, yielding a lump of metal looking similar to tin.[45] Friedrich Wöhler was aware of these experiments and cited them, but after redoing the experiments of Ørsted he concluded that this metal was pure potassium. He conducted a similar experiment in 1827 by mixing anhydrous aluminium chloride with potassium and yielded aluminium.[45] Wöhler is generally credited with isolating aluminium (Latin *alumen*, alum), but also Ørsted can be listed as its discoverer.[46] Further, Pierre Berthier discovered aluminium in bauxite ore and successfully extracted it.[47] Frenchman Henri Etienne Sainte-Claire Deville improved Wöhler's method in 1846, and described his improvements in a book in 1859, chief among these being the substitution of sodium for the considerably more expensive potassium.[48] Deville likely also conceived the idea of the electrolysis of aluminium oxide dissolved in cryolite; Charles Martin Hall and Paul Héroult might have developed the more practical process after Deville.

Before the Hall-Héroult process was developed in the late 1880s, aluminium was exceedingly difficult to extract from its various ores. This made pure aluminium more valuable than gold.[49] Bars of aluminium were exhibited at the Exposition Universelle of 1855.[50] Napoleon III, Emperor of France, is reputed to have given a banquet where the most honoured guests were given aluminium utensils, while the others made do with gold.[51][52]

Aluminium was selected as the material to be used for the 100 ounce (2.8 kg) capstone of the Washington Monument in 1884, a time when one ounce (30 grams) cost the daily wage of a common worker on the project;[53] The capstone, which was set in place on December 6, 1884, in an elaborate dedication ceremony, was the largest single piece of aluminium cast at the time, when aluminium was as expensive as silver.[53]

The Cowles companies supplied aluminium alloy in quantity in the United States and England using smelters like the furnace of Carl Wilhelm Siemens by 1886.[54][55][56] Charles Martin Hall of Ohio in the U.S. and Paul Héroult of France independently developed the Hall-Héroult electrolytic process that made extracting aluminium from minerals cheaper and is now the principal method used worldwide. Hall's process,[57] in 1888 with the financial backing of Alfred E. Hunt, started the Pittsburgh Reduction Company today known as Alcoa. Héroult's process was in production by 1889 in Switzerland at Aluminium Industrie, now Alcan, and at British Aluminium, now Luxfer Group and Alcoa, by 1896 in Scotland.[58]

By 1895, the metal was being used as a building material as far away as Sydney, Australia in the dome of the Chief Secretary's Building.

Many navies have used an aluminium superstructure for their vessels; the 1975 fire aboard USS *Belknap* that gutted her aluminium superstructure, as well as observation of battle damage to British ships during the Falklands War, led to many navies switching to all steel superstructures. The *Arleigh Burke* class was the first such U.S. ship, being constructed entirely of steel.

Aluminium wire was once widely used for domestic electrical wiring. Owing to corrosion-induced failures, a number of fires resulted. This discontinuation thus illustrates one failed application of the otherwise highly useful metal.

Etymology

Two variants of the metal's name are in current use, *aluminium* and *aluminum* (besides the obsolete *alumium*). The International Union of Pure and Applied Chemistry (IUPAC) adopted *aluminium* as the standard international name for the element in 1990 but, three years later, recognized *aluminum* as an acceptable variant. Hence their periodic table includes both.[59] IUPAC prefers the use of *aluminium* in its internal publications, although nearly as many IUPAC publications use the spelling *aluminum*.[60]

Most countries use the spelling *aluminium*. In the United States, the spelling *aluminum* predominates.[14] [61] The Canadian Oxford Dictionary prefers *aluminum*, whereas the Australian Macquarie Dictionary prefers *aluminium*. In 1926, the American Chemical Society officially decided to use *aluminum* in its publications; American dictionaries typically label the spelling *aluminium* as a British variant.

The name *aluminium* derives from its status as a base of alum. It is borrowed from Old French; its ultimate source, *alumen*, in turn is a Latin word that literally means "bitter salt".[62]

The earliest citation given in the Oxford English Dictionary for any word used as a name for this element is *alumium*, which British chemist and inventor Humphry Davy employed in 1808 for the metal he was trying to isolate electrolytically from the mineral *alumina*. The citation is from the journal *Philosophical Transactions of the Royal Society of London*: "Had I been so fortunate as to have obtained more certain evidences on this subject, and to have procured the metallic substances I was in search of, I should have proposed for them the names of silicium, alumium, zirconium, and glucium."[63][64]

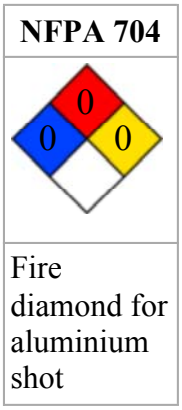
Davy settled on *aluminum* by the time he published his 1812 book *Chemical Philosophy*: "This substance appears to contain a peculiar metal, but as yet Aluminum has not been obtained in a perfectly free state, though alloys of it with other metalline substances have been procured sufficiently distinct to indicate the probable nature of alumina."[65] But the same year, an anonymous contributor to the *Quarterly Review,* a British political-literary journal, in a review of Davy's book, objected to *aluminum* and proposed the name *aluminium*, "for so we shall take the liberty of writing the word, in preference to aluminum, which has a less classical sound."[66]

The *-ium* suffix conformed to the precedent set in other newly discovered elements of the time: potassium, sodium, magnesium, calcium, and strontium (all of which Davy isolated himself). Nevertheless, *-um* spellings for elements were not unknown at the time, as for example platinum, known to Europeans since the 16th century, molybdenum, discovered in 1778, and tantalum, discovered in 1802. The *-um* suffix is consistent with the universal spelling alumina for the oxide, as lanthana is the oxide of lanthanum, and magnesia, ceria, and thoria are the oxides of magnesium, cerium, and thorium respectively.

The spelling used throughout the 19th century by most U.S. chemists was *aluminium*, but common usage is less clear.[67] The *aluminum* spelling is used in the Webster's Dictionary of 1828. In his advertising handbill for his new electrolytic method of producing the metal 1892, Charles Martin Hall used the *-um* spelling, despite his constant use of the *-ium* spelling in all the patents[57] he filed between 1886 and 1903.[68] It has consequently been suggested that the spelling reflects an easier to pronounce word with one fewer syllable, or that the spelling on the flier was a mistake. Hall's domination of production of the metal ensured that the spelling *aluminum* became the standard in North America; the *Webster Unabridged Dictionary* of 1913, though, continued to use the *-ium* version.

Health concerns

Despite its natural abundance, aluminium has no known function in biology. It is remarkably nontoxic, aluminium sulfate having an LD50 of 6207 mg/kg (oral, mouse), which corresponds to 500 grams for a 80 kg person.[5] Despite the extremely low acute toxicity, the health effects of aluminium are of interest in view of the widespread occurrence of the element in the environment and in commerce.



Fire diamond for aluminium shot

Some toxicity can be traced to deposition in bone and the central nervous system, which is particularly increased in patients with reduced renal function. Because aluminium competes with calcium for absorption, increased amounts of dietary aluminium may contribute to the reduced skeletal mineralization (osteopenia) observed in preterm infants and infants with growth retardation. In very high doses, aluminium can cause neurotoxicity, and is associated with altered function of the blood–brain barrier.[69] A small percentage of people are allergic to aluminium and experience contact dermatitis, digestive disorders, vomiting or other symptoms upon contact or ingestion of products containing aluminium, such as deodorants or antacids. In those without allergies, aluminium is not as toxic as heavy metals, but there is evidence of some toxicity if it is consumed in excessive amounts.[70] Although the use of aluminium cookware has not been shown to lead to aluminium toxicity in general, excessive consumption of antacids containing aluminium compounds and excessive use of aluminium-containing antiperspirants provide more significant exposure levels. Studies have shown that consumption of acidic foods or liquids with aluminium significantly increases aluminium absorption,[71] and maltol has been shown to increase the accumulation of aluminium in nervous and osseus tissue.[72] Furthermore, aluminium increases estrogen-related gene expression in human breast cancer cells cultured in the laboratory.[73] The estrogen-like effects of these salts have led to their classification as a metalloestrogen.

The effects of aluminium in antiperspirants has been examined over the course of decades with little evidence of skin irritation.[5] Nonetheless, its occurrence in antiperspirants, dyes (such as aluminium lake), and food additives is controversial in some quarters. Although there is little evidence that normal exposure to aluminium presents a risk to healthy adults,[74] some studies point to risks associated with increased exposure to the metal.[75] Aluminium in food may be absorbed more than aluminium from water.[76] Some researchers have expressed concerns that the aluminium in antiperspirants may increase the risk of breast cancer,[77] and aluminium has controversially been implicated as a factor in Alzheimer's disease.[78] The Camelford water pollution incident involved a number of people consuming

aluminium sulfate. Investigations of the long-term health effects are still ongoing, but elevated brain aluminium concentrations have been found in post-mortem examinations of victims, and further research to determine if there is a link with cerebral amyloid angiopathy has been commissioned.[79]

According to The Alzheimer's Society, the overwhelming medical and scientific opinion is that studies have not convincingly demonstrated a causal relationship between aluminium and Alzheimer's disease.[80] Nevertheless, some studies, such as those on the PAQUID cohort,[81] cite aluminium exposure as a risk factor for Alzheimer's disease. Some brain plaques have been found to contain increased levels of the metal.[82] Research in this area has been inconclusive; aluminium accumulation may be a consequence of the disease rather than a causal agent. In any event, if there is any toxicity of aluminium, it must be via a very specific mechanism, since total human exposure to the element in the form of naturally occurring clay in soil and dust is enormously large over a lifetime.[83][84] Scientific consensus does not yet exist about whether aluminium exposure could directly increase the risk of Alzheimer's disease.[80]

Effect on plants

Aluminium is primary among the factors that reduce plant growth on acid soils. Although it is generally harmless to plant growth in pH-neutral soils, the concentration in acid soils of toxic Al^{3+} cations increases and disturbs root growth and function.[85][86][87][88]

Most acid soils are saturated with aluminium rather than hydrogen ions. The acidity of the soil is therefore a result of hydrolysis of aluminium compounds.[89] This concept of "corrected lime potential"[90] to define the degree of base saturation in soils became the basis for procedures now used in soil testing laboratories to determine the "lime requirement"[91] of soils.[92]

Wheat's adaptation to allow aluminium tolerance is such that the aluminium induces a release of organic compounds that bind to the harmful aluminium cations. Sorghum is believed to have the same tolerance mechanism. The first gene for aluminium tolerance has been identified in wheat. It was shown that sorghum's aluminium tolerance is controlled by a single gene, as for wheat.[93] This is not the case in all plants.

See also

- *Aluminium: The Thirteenth Element*
- Aluminium–air battery
- Aluminium alloy
- Aluminium foil
- Aluminium hydroxide
- Aluminium in Russia
- Beverage can
- Institute for the History of Aluminium
- Panel edge staining
- The Aluminum Association
- Quantum clock
- List of countries by aluminium production

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