Aluminium

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This article is about the metallic element. For other uses, see Aluminium (disambiguation).

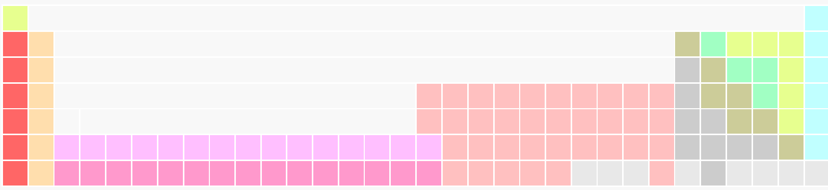
Aluminium, $_{13}$Al

Spectral lines of aluminium

General properties

Name, symbol	aluminium, Al
Appearance	silvery gray metallic
Pronunciation	UK /ˌæljʊˈmɪniəm/ *AL-ew-MIN-ee-əm* US /əˈljuːmɪnəm/ *ə-LEW-mi-nəm*
Alternative name	aluminum (US)

Aluminium in the periodic table



B
↑
Al
↓
Ga

magnesium ← **aluminium** → silicon

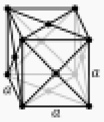
Atomic number (*Z*)	13
Group, block	group 13, p-block

Period	period 3
Element category	▯ post-transition metal, sometimes considered ametalloid
Standard atomic weight (±) (A_r)	26.9815385(7)[1]
Electron configuration	[Ne] $3s^2$ $3p^1$
per shell	2, 8, 3
Physical properties	
Phase	solid
Melting point	933.47 K (660.32 °C, 1220.58 °F)
Boiling point	2743 K (2470 °C, 4478 °F)
Density near r.t.	2.70 g/cm^3
when liquid, at m.p.	2.375 g/cm^3
Heat of fusion	10.71 kJ/mol
Heat of vaporization	284 kJ/mol
Molar heat capacity	24.20 J/(mol·K)

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,[2] +1[3], −1, −2 (anamphoteric oxide)
Electronegativity	Pauling scale: 1.61
Ionization energies	1st: 577.5 kJ/mol 2nd: 1816.7 kJ/mol 3rd: 2744.8 kJ/mol (more)

Atomic radius	empirical: 143 pm
Covalent radius	121±4 pm
Van der Waals radius	184 pm
Miscellanea	
Crystal structure	face-centered cubic (fcc) 
Speed of sound thin rod	(rolled) 5000 m/s (at r.t.)
Thermal expansion	23.1 µm/(m·K) (at 25 °C)
Thermal conductivity	237 W/(m·K)
Electrical resistivity	28.2 nΩ·m (at 20 °C)
Magnetic ordering	paramagnetic[4]
Young's modulus	70 GPa
Shear modulus	26 GPa
Bulk modulus	76 GPa
Poisson ratio	0.35
Mohs hardness	2.75
Vickers hardness	160–350 MPa
Brinell hardness	160–550 MPa
CAS Number	7429-90-5
History	
Prediction	Antoine Lavoisier[5] (1787)
First isolation	Hans Christian Ørsted[6](1825)

Named by	Humphry Davy[5] (1807)

Most stable isotopes of aluminium

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

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Aluminium (in Commonwealth English) or **aluminum** (in American English) is a chemical element in the boron group with symbol **Al** and atomic number 13. It is a silvery-white, soft, nonmagnetic, ductile metal. Aluminium is the third most abundant element in the Earth's crust (after oxygen and silicon) and its most abundant metal. Aluminium makes up about 8% of the crust by mass, though it is less common in the mantle below. Aluminium metal is so chemically reactive that native specimens are rare and limited to extreme reducing environments. Instead, it is found combined in over 270 different minerals.[7] The chief ore of aluminium is bauxite.

Aluminium is remarkable for the metal's low density and its ability to resist corrosion through the phenomenon ofpassivation. Aluminium and its alloys are vital to the aerospace industry and important in transportation and structures, such as building facades and window frames.[clarification needed] The oxides and sulfates are the most useful compounds of aluminium.[citation needed]

Despite its prevalence in the environment, no known form of life uses aluminium salts metabolically, but aluminium is well tolerated by plants and animals.[8] Because of their abundance, the potential for a biological role is of continuing interest and studies continue.

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Characteristics

"Bauxite tailings" storage facility inStade, Germany. The aluminium industry generates about 70 million tons of this waste annually.

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 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.[9] Aluminium has about one-third the density andstiffness 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.[10]

Aluminium is a good thermal and electrical conductor, having 59% the conductivity of copper, both thermal and electrical, while having only 30% of copper's density. Aluminium is capable of superconductivity, with a superconducting critical temperature of 1.2 kelvin and a critical magnetic field of about 100 gauss (10 milliteslas).[11]

Chemical

Corrosion resistance can be excellent because a thin surface layer of aluminium oxide forms when the bare metal is exposed to air, effectively preventing further oxidation.[12] The strongest aluminium alloys are less corrosion resistant due to galvanic reactions with alloyed copper.[9] This corrosion resistance is greatly reduced by aqueous salts, particularly in the presence of dissimilar metals.

In highly acidic solutions, aluminium reacts with water to form hydrogen, and in highly alkaline ones to formaluminates— protective passivation under these conditions is negligible. Primarily because it is corroded by dissolved chlorides, such as common sodium chloride, household plumbing is never made from aluminium.[13]

However, because of its general resistance to corrosion, aluminium is one of the few metals that retains 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 nm (near IR) bysilver, gold, and copper.[14]

Aluminium is oxidized by water at temperatures below 280 °C to produce hydrogen, aluminium hydroxide and heat:

$$2\ Al + 6\ H_2O \rightarrow 2\ Al(OH)_3 + 3\ H_2$$

This conversion is of interest for the production of hydrogen. However, commercial application of this fact has challenges in circumventing the passivating oxide layer, which inhibits the reaction, and in storing the energy required to regenerate the aluminium metal.[15]

Isotopes

Main article: Isotopes of aluminium

Aluminium has many known isotopes, with mass numbers range from 21 to 42; however, only ^{27}Al (stable) and ^{26}Al (radioactive, $t_{1/2}$ = 7.2×10^5 y) occur naturally. ^{27}Al has a natural abundance above 99.9%. ^{26}Al is produced from argon in theatmosphere by spallation caused by cosmic-ray protons. Aluminium isotopes are useful 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 transport, deposition, sediment storage, burial times, and erosion on 10^5 to 10^6 year time scales.[16] 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.[17]

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.[18] It is estimated to be the 14th most common element in the Universe, by mass-fraction.[19] However, among the elements that have odd atomic numbers, aluminium is the third most abundant by mass fraction, after hydrogen and nitrogen.[19]

In the Earth's crust, aluminium is the most abundant (8.3% by mass) metallic element and the third most abundant of all elements (after oxygen and silicon).[20] The Earth's crust has a greater abundance of aluminium than the rest of the planet, primarily in aluminium silicates. In the Earths mantle, which is only 2% aluminium by mass, these aluminium silicate minerals are largely replaced by silica and magnesium oxides. Overall, the Earth is about 1.4% aluminium by mass (eighth in abundance by mass). Aluminium occurs in greater proportion in the Earth than in the Solar system and Universe because the more common elements (hydrogen, helium, neon, nitrogen, carbon as hydrocarbon) are volatile at Earth's proximity to the Sun and large quantities of those were lost.

Because of its strong affinity for oxygen, aluminium 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 fugacityenvironments, such as the interiors of certain volcanoes.[21] Native aluminium has been reported in cold seeps in the northeastern continental slope of the South China Sea. Chen *et al.* (2011)[22] propose the theory that these deposits resulted from bacterialreduction of tetrahydroxoaluminate $Al(OH)_4^-$.[22]

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

Although aluminium is a common and widespread element, not all aluminium minerals are economically viable 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.[23] Bauxite is mined from large deposits in Australia, Brazil, Guinea, and Jamaica; it is also mined from lesser deposits in China, India, Indonesia, 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 color is due to the presence of iron minerals.

Bayer process and Hall-Héroult processes

Bauxite is converted to aluminium oxide (Al_2O_3) by the Bayer process.[8] Relevant chemical equations are:

$Al_2O_3 + 2\ NaOH \rightarrow 2\ NaAlO_2 + H_2O$
$2\ H_2O + NaAlO_2 \rightarrow Al(OH)_3 + NaOH$

The intermediate, sodium aluminate, with the simplified formula $NaAlO_2$, is soluble in strongly alkaline water, and the other components of the ore are not. Depending on the quality of the bauxite ore, twice as much waste ("Bauxite tailings") as alumina is generated.

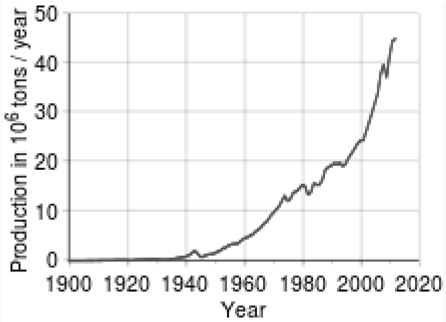
The conversion of alumina to aluminium metal is achieved by the Hall-Héroult process. In this energy-intensive process, a solution of alumina in a molten (950 and 980 °C (1,740 and 1,800 °F)) mixture of cryolite (Na_3AlF_6) with calcium fluoride iselectrolyzed to produce metallic aluminium:

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

The liquid aluminium metal sinks to the bottom of the solution and is tapped off, and usually cast into large blocks called aluminium billets for further processing. Oxygen is produced at the anode:

$2\ O^{2-} + C \rightarrow CO_2 + 4\ e^-$

The carbon anode is consumed by reaction with oxygen to form carbon dioxide gas, with a small quantity of fluoride gases. In modern smelters, the gas is filtered through alumina to remove fluorine compounds and return aluminium fluoride to the electrolytic cells. The anode this reduction cell must be replaced regularly, since it is consumed in the process. The cathode is also eroded, mainly by electrochemical processes and liquid metal movement induced by intense electrolytic currents. After five to ten years, depending on the current used in the electrolysis, a cell must be rebuilt because of cathode wear.



World production trend of aluminium

Aluminium electrolysis with the Hall-Héroult process consumes a lot of energy. The worldwide average specific energy consumption is approximately 15±0.5 kilowatt-hours per kilogram of aluminium produced (52 to 56 MJ/kg). Some 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.) Minimizing 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]

The Hall-Heroult process produces aluminium with a purity of above 99%. Further purification can be done by the Hoopes process. This process involves the electrolysis of molten aluminium with a sodium, barium and aluminium fluoride electrolyte. The resulting aluminium has a purity of 99.99%.[8][24]

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.[25] Aluminium producers tend to locate smelters in places where electric power is both plentiful and inexpensive—such as the United Arab Emirates with its large natural gas supplies,[26] and Iceland[27]and Norway[28] with energy generated from renewable sources. The world's largest smelters of alumina are located in the People's Republic of China, Russia and the provinces of Quebec and British Columbia in Canada.[25][29][30]

Aluminium spot price 1987–2012

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 US, reports the British Geological Survey.

Over the last 50 years, Australia has become the world's top producer of bauxite ore and a major producer and exporter of alumina (before being overtaken by China in 2007).[29][31] Australia produced 77 million tonnes of bauxite in 2013.[32] The Australian deposits have some refining problems, some being high in silica, but have the advantage of being shallow and relatively easy to mine.[33]