What is Lithium?

Lithium, from the Greek "lithos" meaning stone, is a chemical element with the symbol Li and atomic number 3. It is a soft, silvery-white, alkali metal and is both the lightest metal and the lightest solid element. Like all alkali metals it is highly reactive and flammable and must be stored in mineral oil. It does not occur freely in nature but only within other compounds. Due to its solubility as an ion it is present in seawater and commonly obtained from brines.

Lithium carbonate is the key raw material in lithium-ion battery manufacturing. Over recent years these have become the principal rechargeable batteries for use in electric vehicles and mobile phones and for the storage of power generated by both wind turbines and solar panels. Lithium is also used as a component in engineering grease, glass manufacture and in medication used to treat depression. It is a possible component in the next generation of fusion reactors.

What is Lithium Carbonate?

Lithium carbonate is an inorganic compound, the lithium salt of carbonate with the formula Li2CO3. This white salt is widely used in the processing of metal oxides and treatment of mood disorders.

For the treatment of bipolar disorder, it is on the World Health Organization's List of Essential Medicines, the most important medications needed in a basic health system.

Lithium carbonate is an important industrial chemical. It forms low-melting fluxes with silica and other materials. Glasses derived from lithium carbonate are useful in ovenware. Lithium carbonate is a common ingredient in both low-fire and high-fire ceramic glaze. Its alkaline properties are conducive to changing the state of metal oxide colorants in glaze particularly red iron oxide (Fe2O3). Cement sets more rapidly when prepared with lithium carbonate, and is useful for tile adhesives. When added to aluminium trifluoride, it forms LiF which gives a superior electrolyte for the processing of aluminium. It is also used in the manufacture of most lithium-ion battery cathodes, which are made of lithium cobalt oxide.

As Albemarle (NYSE:ALB, The world's largest lithium extraction company) notes, lithium carbonate is often "the first chemical in the lithium production chain," with compounds like lithium hydroxide being produced with subsequent steps if needed. For that reason, lithium production numbers are often broken down in terms of lithium carbonate equivalent - LCE. Lithium carbonate is generated by combining lithium peroxide with carbon dioxide.

Like other lithium products, lithium carbonate may be produced from brines or from hard-rock deposits. That said, a few companies are also looking to produce the material from clay-based lithium deposits.

Though many companies are interested in producing lithium carbonate, not all investors are familiar with what it is. Here are a few key points on lithium carbonate to keep in mind. Each point is elaborated on further in the article below:

1. Lithium carbonate is used for much more than just lithium-ion batteries.
2. Not all lithium carbonate is created equal.
3 Lithium hydroxide is becoming more popular than lithium carbonate for use in manufacturing lithium-ion batteries, particularly for use in vehicles. So much so that according to Reuters, in 2019 POSCO, the South Korean steel pulled out of a deal made in 2018 with Samsung and the Chilean Government for a 27 year licence for low cost lithium in return for building a battery factory in Chile. The principal reason given was that Albemarle (The world's largest lithium mining company) are producing lithium carbonate, when the South Koreans have switched their preference to lithium hydroxide.

1. Lithium carbonate: Batteries and beyond

Batteries have generated the most excitement in the lithium space over the last few years, with interest spurred by Tesla's (NASDAQ:TSLA) plans to develop lithium-ion battery gigafactories. However, there is more to the lithium market than Tesla, and the market for lithium is not all about batteries.

Looking beyond batteries, lithium carbonate is used in ceramics, glass, cement and aluminum processing. Indeed, while the battery market is certainly growing, the US Geological Survey estimates that glass and ceramics still made up roughly 27 percent of global end-use markets in 2017. Lithium carbonate also has an important use in the pharmaceutical industry: it's been on the World Health Organisation's list of essential medicines as a treatment for bipolar disorder.

2. Lithium production: Different types of lithium

When it comes to lithium production, not all lithium carbonate is made equal, and end products must meet specific requirements to be used in different applications. For example, battery-grade lithium carbonate can be used to make cathode material for lithium-ion batteries, but most contaminants must be removed in order for the material to be considered battery grade.

Technical-grade lithium carbonate is cheaper than battery-grade material, but such products must have very low concentrations of iron to make the cut for end users. This type of lithium is used in applications for glass and ceramics. It's also worth noting that lithium is used in the form of ore concentrates in industrial applications rather than as lithium carbonate or hydroxide.

3. What about hydroxide?

As mentioned, lithium hydroxide is becoming more popular than lithium carbonate, at least in terms of manufacturing electric vehicle batteries. While lithium hydroxide is more expensive, it can also be used to produce cathode material more efficiently, and is actually necessary for some types of cathodes, such as nickel–cobalt-aluminum oxide (NCA) and nickel-manganese-cobalt oxide (NMC).

As Jean Francois Magnan, technical manager for Nemaska Lithium (TSXV:NMX), once explained in an interview, "because hydroxide decomposes at a lower temperature, it accelerates the process. It uses less heat, less energy, so you produce more cathode material with less energy, and you can still use the same equipment."

Demand for lithium production has risen significantly in recent years due to the growing electric vehicle market, and lithium hydroxide is expected to outpace lithium carbonate in terms of demand growth.

That might not sound like good news for lithium carbonate, but as explained above, the material still has plenty of uses beyond batteries. And since it's still a precursor to lithium hydroxide in most cases, lithium carbonate could still have a place in the lithium-ion battery supply chain moving forward.

Due to its solubility as an ion, lithium is present in ocean water and is commonly obtained from brines. Lithium metal is isolated electrolytically from a mixture of lithium chloride and potassium chloride.

The nucleus of the lithium atom verges on instability, since the two stable lithium isotopes found in nature have among the lowest binding energies per nucleon of all stable nuclides. Because of its relative nuclear instability, lithium is less common in the solar system than 25 of the first 32 chemical elements even though its nuclei are very light: it is an exception to the trend that heavier nuclei are less common.[2] For related reasons, lithium has important uses in nuclear physics. The transmutation of lithium atoms to helium in 1932 was the first fully man-made nuclear reaction, and lithium deuteride serves as a fusion fuel in staged thermonuclear weapons.[3]

Lithium and its compounds have several industrial applications, including heat-resistant glass and ceramics, lithium grease lubricants, flux additives for iron, steel and aluminium production, lithium batteries, and lithium-ion batteries. These uses consume more than three quarters of lithium production.

Lithium is present in biological systems in trace amounts; its functions are uncertain. Lithium salts have proven to be useful as a mood-stabilizing drug in the treatment of bipolar disorder in humans.

Properties

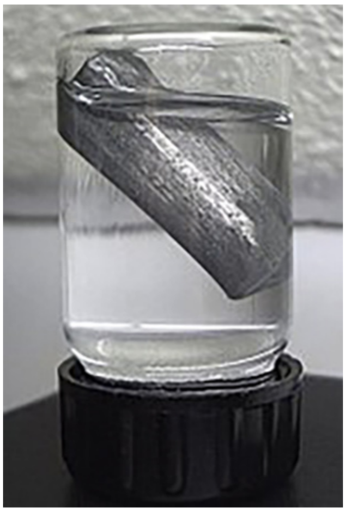
Atomic and physical

Lithium ingots with a thin layer of black nitride tarnish

Like the other alkali metals, lithium has a single valence electron that is easily given up to form a cation.[4] Because of this, lithium is a good conductor of heat and electricity as well as a highly reactive element, though it is the least reactive of the alkali metals. Lithium's low reactivity is due to the proximity of its valence electron to its nucleus (the remaining two electrons are in the 1s orbital, much lower in energy, and do not participate in chemical bonds).[4] However, molten lithium is significantly more reactive than its solid form.[5][6]

Lithium metal is soft enough to be cut with a knife. When cut, it possesses a silvery-white colour that quickly changes to grey as it oxidises to lithium oxide.[4] While it has one of the lowest melting points among all metals (180 °C, 453 K), it has the highest melting and boiling points of the alkali metals.[7]

Lithium has a very low density (0.534 g/cm3), comparable with pine wood[8]. It is the least dense of all elements that are solids at room temperature; the next lightest solid element (potassium, at 0.862 g/cm3) is more than 60% denser. Furthermore, apart from helium and hydrogen, as a solid it is less dense than any other element as a liquid, being only two thirds as dense as liquid nitrogen (0.808 g/cm3).[9] Lithium can float on the lightest hydrocarbon oils and is one of only three metals that can float on water, the other two being sodium and potassium.



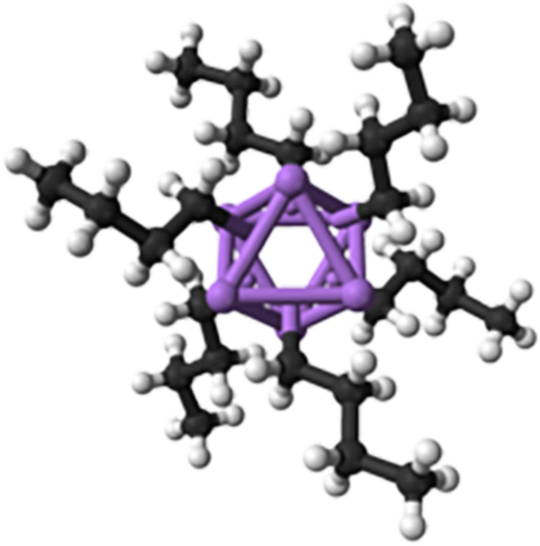
Lithium floating in oil

Lithium's coefficient of thermal expansion is twice that of aluminium and almost four times that of iron.[10] Lithium is superconductive below 400 μK at standard pressure[11] and at higher temperatures (more than 9 K) at very high pressures (>20 GPa).[12] At temperatures below 70 K, lithium, like sodium, undergoes diffusionless phase change transformations. At 4.2 K it has a rhombohedral crystal system (with a nine-layer repeat spacing); at higher temperatures it transforms to face-centered cubic and then body-centered cubic. At liquid-helium temperatures (4 K) the rhombohedral structure is prevalent.[13] Multiple allotropic forms have been identified for lithium at high pressures.[14]

Lithium has a mass specific heat capacity of 3.58 kilojoules per kilogram-kelvin, the highest of all solids.[15][16] Because of this, lithium metal is often used in coolants for heat transfer applications.[15]

Chemistry and compounds

Lithium reacts with water easily, but with noticeably less vigour than other alkali metals. The reaction forms hydrogen gas and lithium hydroxide in aqueous solution.[4] Because of its reactivity with water, lithium is usually stored in a hydrocarbon sealant, often petroleum jelly. Though the heavier alkali metals can be stored in more dense substances, such as mineral oil, lithium is not dense enough to be fully submerged in these liquids.[17] In moist air, lithium rapidly tarnishes to form a black coating of lithium hydroxide (LiOH and LiOH·H2O), lithium nitride (Li3N) and lithium carbonate (Li2CO3, the result of a secondary reaction between LiOH and CO2).[18]



Hexameric structure of the n-butyllithium fragment in a crystal

When placed over a flame, lithium compounds give off a striking crimson colour, but when it burns strongly the flame becomes a brilliant silver. Lithium will ignite and burn in oxygen when exposed to water or water vapours.[19] Lithium is flammable, and it is potentially explosive when exposed to air and especially to water, though less so than the other alkali metals. The lithium-water reaction at normal temperatures is brisk but nonviolent because the hydrogen produced does not ignite on its own. As with all alkali metals, lithium fires are difficult to extinguish, requiring dry powder fire extinguishers (Class D type). Lithium is one of the few metals that react with nitrogen under normal conditions.[20][21]

Lithium has a diagonal relationship with magnesium, an element of similar atomic and ionic radius. Chemical resemblances between the two metals include the formation of a nitride by reaction with N_2, the formation of an oxide ($Li_2$2O) and peroxide ($Li_2$2$O_2$2) when burnt in O2, salts with similar solubilities, and thermal instability of the carbonates and nitrides.[18][22] The metal reacts with hydrogen gas at high temperatures to produce lithium hydride (LiH).[23]

Other known binary compounds include halides (LiF, LiCl, LiBr, LiI), sulfide ($Li_2$2S), superoxide ($LiO_2$2), and carbide ($Li_2$2$C_2$2). Many other inorganic compounds are known in which lithium combines with anions to form salts: borates, amides, carbonate, nitrate, or borohydride ($LiBH_2$4). Lithium aluminium hydride ($LiAlH_2$4) is commonly used as a reducing agent in organic synthesis.

LiHe, a very weakly interacting van der Waals compound, has been detected at very low temperatures.[24]

Unlike other elements in group 1, inorganic compounds of lithium follow the **duet rule**, rather than the octet rule.

Organic chemistry

Organolithium reagents are known in which there is a direct bond between carbon and lithium atoms. These compounds feature covalent metal–carbon bonds that are strongly polarised towards the carbon, allowing them to effectively serve as a metal-stabilised carbanions, although their solution and solid-state structures are more complex than this simplistic view suggests due to the formation of oligomeric clusters.[25] Thus, these are extremely powerful bases and nucleophiles. They have also been applied in asymmetric synthesis in the pharmaceutical industry. For laboratory organic synthesis, many organolithium reagents are commercially available in solution form. These reagents are highly reactive, and are sometimes pyrophoric.

Like its inorganic compounds, almost all organic compounds of lithium formally follow the duet rule (e.g., BuLi, MeLi). However, it is important to note that in the absence of coordinating solvents or ligands, organolithium compounds form dimeric, tetrameric, and hexameric clusters (e.g., BuLi is actually [BuLi]6 and MeLi is actually [MeLi]4) which feature multi-centre bonding and increase the coordination number around lithium. These cluster are broken down into smaller or monomeric units in the presence of solvents like dimethoxyethane (DME) or ligands like tetramethylethylenediamine (TMEDA).[26] As an exception to the duet rule, a two-coordinate lithate complex with four electrons around lithium, [Li(thf)4]+[((Me3Si)3C)2Li]–, has been characterised crystallographically.[27]

Isotopes

Naturally occurring lithium is composed of two stable isotopes, 6Li and 7Li, the latter being the more abundant (92.5% natural abundance).[4][17][28] Both natural isotopes have anomalously low nuclear binding energy per nucleon (compared to the neighbouring elements on the periodic table, helium and beryllium); lithium is the only low numbered element that can produce net energy through nuclear fission. The two lithium nuclei have lower binding energies per nucleon than any other stable nuclides other than deuterium and helium-3.[29] As a result of this, though very light in atomic weight, lithium is less common in the Solar System than 25 of the first 32 chemical elements.[2] Seven radioisotopes have been characterised, the most stable being 8Li with a half-life of 838 ms and 9Li with a half-life of 178 ms. All of the remaining radioactive isotopes have half-lives that are shorter than 8.6 ms. The shortest-lived isotope of lithium is 4Li, which decays through proton emission and has a half-life of 7.6 × 10−23 s.[30]

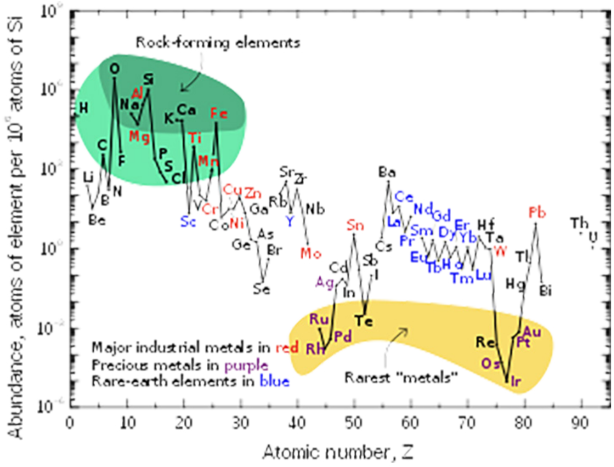
7Li is one of the primordial elements (or, more properly, primordial nuclides) produced in Big Bang nucleosynthesis. A small amount of both 6Li and 7Li are produced in stars, but are thought to be "burned" as fast as produced.[31] Additional small amounts of lithium of both 6Li and 7Li may be generated from solar wind, cosmic rays hitting heavier atoms, and from early solar system 7Be and 10Be radioactive decay.[32] While lithium is created in stars during stellar nucleosynthesis, it is further burned. 7Li can also be generated in carbon stars.[33]

Lithium isotopes fractionate substantially during a wide variety of natural processes,[34] including mineral formation (chemical precipitation), metabolism, and ion exchange. Lithium ions substitute for magnesium and iron in octahedral sites in clay minerals, where 6Li is preferred to 7Li, resulting in enrichment of the light isotope in processes of hyperfiltration and rock alteration. The exotic 11Li is known to exhibit a nuclear halo. The process known as laser isotope separation can be used to separate lithium isotopes, in particular 7Li from 6Li.[35]

Nuclear weapons manufacture and other nuclear physics applications are a major source of artificial lithium fractionation, with the light isotope 6Li being retained by industry and military stockpiles to such an extent that it has caused slight but measurable change in the 6Li to 7Li ratios in natural sources, such as rivers. This has led to unusual uncertainty in the standardised atomic weight of lithium, since this quantity depends on the natural abundance ratios of these naturally-occurring stable lithium isotopes, as they are available in commercial lithium mineral sources.[36]

Both stable isotopes of lithium can be laser cooled and were used to produce the first quantum degenerate Bose-Fermi mixture.[37]

Occurrence



Lithium is about as common as chlorine in the Earth's upper continental crust, on a per-atom basis.

Astronomical

Though it was synthesised in the Big Bang, lithium (together with beryllium and boron) is markedly less abundant in the universe than other elements. This is a result of the comparatively low stellar temperatures necessary to destroy lithium, along with a lack of common processes to produce it.[38]

According to modern cosmological theory, lithium—in both stable isotopes (lithium-6 and lithium-7)—was one of the three elements synthesised in the Big Bang.[39] Though the amount of lithium generated in Big Bang nucleosynthesis is dependent upon the number of photons per baryon, for accepted values the lithium abundance can be calculated, and there is a "cosmological lithium discrepancy" in the universe: older stars seem to have less lithium than they should, and some younger stars have much more.[40] The lack of lithium in older stars is apparently caused by the "mixing" of lithium into the interior of stars, where it is destroyed,[41] while lithium is produced in younger stars. Though it transmutes into two atoms of helium due to collision with a proton at temperatures above 2.4 million degrees Celsius (most stars easily attain this temperature in their interiors), lithium is more abundant than current computations would predict in later-generation stars.[17]

Nova Centauri 2013 is the first in which evidence of lithium has been found.[42]

Lithium is also found in brown dwarf substellar objects and certain anomalous orange stars. Because lithium is present in cooler, less-massive brown dwarfs, but is destroyed in hotter red dwarf stars, its presence in the stars' spectra can be used in the "lithium test" to differentiate the two, as both are smaller than the Sun.[17][43][44] Certain orange stars can also contain a high concentration of lithium. Those orange stars found to have a higher than usual concentration of lithium (such as Centaurus X-4) orbit massive objects—neutron stars or black holes—whose gravity evidently pulls heavier lithium to the surface of a hydrogen-helium star, causing more lithium to be observed.[17]

Terrestrial

Although lithium is widely distributed on Earth, it does not naturally occur in elemental form due to its high reactivity.[4] The total lithium content of seawater is very large and is estimated as 230 billion tonnes, where the element exists at a relatively constant concentration of 0.14 to 0.25 parts per million (ppm),[45][46] or 25 micromolar;[47] higher concentrations approaching 7 ppm are found near hydrothermal vents.[46]

Estimates for the Earth's crustal content range from 20 to 70 ppm by weight.[18] In keeping with its name, lithium forms a minor part of igneous rocks, with the largest concentrations in granites. Granitic pegmatites also provide the greatest abundanc e of lithium-containing minerals, with spodumene and petalite being the most commercially viable sources.[18] Another significant mineral of lithium is lepidolite which is now an obsolete name for a series formed by polylithionite and trilithionite.[48][49] A newer source for lithium is hectorite clay, the only active development of which is through the Western Lithium

Corporation in the United States.[50] At 20 mg lithium per kg of Earth's crust,[51] lithium is the 25th most abundant element.

According to the Handbook of Lithium and Natural Calcium, "Lithium is a comparatively rare element, although it is found in many rocks and some brines, but always in very low concentrations. There are a fairly large number of both lithium mineral and brine deposits but only comparatively few of them are of actual or potential commercial value. Many are very small, others are too low in grade."[52]

The US Geological Survey estimates that in 2010, Chile had the largest reserves by far (7.5 million tonnes)[53] and the highest annual production (8,800 tonnes). One of the largest reserve bases[note 1] of lithium is in the Salar de Uyuni area of Bolivia, which has 5.4 million tonnes. Other major suppliers include Australia, Argentina and China.[54][55] As of 2015, the Czech Geological Survey considered the entire Ore Mountains in the Czech Republic as lithium province. Five deposits are registered, one near Cínovec [cs] is considered as a potentially economical deposit, with 160 000 tonnes of lithium.[56]. In December 2019, Finnish mining company Keliber Oy reported its Rapasaari lithium deposit has estimated proven and probable ore reserves of 5.280 million tonnes.[57]

In June 2010, The New York Times reported that American geologists were conducting ground surveys on dry salt lakes in western Afghanistan believing that large deposits of lithium are located there. "Pentagon officials said that their initial analysis at one location in Ghazni Province showed the potential for lithium deposits as large as those of Bolivia, which now has the world's largest known lithium reserves."[58] These estimates are "based principally on old data, which was gathered mainly by the Soviets during their occupation of Afghanistan from 1979–1989". Stephen Peters, the head of the USGS's Afghanistan Minerals Project, said that he was unaware of USGS involvement in any new surveying for minerals in Afghanistan in the past two years. 'We are not aware of any discoveries of lithium,' he said."[59]

Biological

Lithium is found in trace amount in numerous plants, plankton, and invertebrates, at concentrations of 69 to 5,760 parts per billion (ppb). In vertebrates the concentration is slightly lower, and nearly all vertebrate tissue and body fluids contain lithium ranging from 21 to 763 ppb.[46] Marine organisms tend to bioaccumulate lithium more than terrestrial organisms.[61] Whether lithium has a physiological role in any of these organisms is unknown.[46]

History

Johan August Arfwedson is credited with the discovery of lithium in 1817

Petalite ($LiAlSi_4O_{10}$) was discovered in 1800 by the Brazilian chemist and statesman José Bonifácio de Andrada e Silva in a mine on the island of Utö, Sweden.[62][63][64][65] However, it was not until 1817 that Johan August Arfwedson, then working in the laboratory of the chemist Jöns Jakob Berzelius, detected the presence of a new element while analysing petalite ore.[66][67][68][69] This element formed compounds similar to those of sodium and potassium, though its carbonate and hydroxide were less soluble in water and less alkaline.[70] Berzelius gave the alkaline material the name "lithion/lithina", from the Greek word λιθoς (transliterated as lithos, meaning "stone"), to reflect its discovery in a solid mineral, as opposed to potassium, which had been discovered in plant ashes, and sodium, which was known partly for its high abundance in animal blood. He named the metal inside the material "lithium".[4][64][69]

Arfwedson later showed that this same element was present in the minerals spodumene and lepidolite.[71][64] In 1818, Christian Gmelin was the first to observe that lithium salts give a bright red colour to flame.[64][72] However, both Arfwedson and Gmelin tried and failed to isolate the pure element from its salts.[64][69][73] It was not isolated until 1821, when William Thomas Brande obtained it by electrolysis of lithium oxide, a process that had previously been employed by the chemist Sir Humphry Davy to isolate the alkali metals potassium and sodium.[17][73][74][75][76] Brande also described some pure salts of lithium, such as the chloride, and, estimating that lithia (lithium oxide) contained about 55% metal, estimated the atomic weight of lithium to be around 9.8 g/mol (modern value ~6.94 g/mol).[77] In 1855, larger quantities of lithium were produced through the electrolysis of lithium chloride by Robert Bunsen and Augustus Matthiessen.[64][78] The discovery of this procedure led to commercial production of lithium in 1923 by the German company Metallgesellschaft AG, which performed an electrolysis of a liquid mixture of lithium chloride and potassium chloride.[64][79][80]

The production and use of lithium underwent several drastic changes in history. The first major application of lithium was in high-temperature lithium greases for aircraft engines and similar applications in World War II and shortly after. This use was supported by the fact that lithium-based soaps have a higher melting point than other alkali soaps, and are less corrosive than calcium based soaps. The small demand for lithium soaps and lubricating greases was supported by several small mining operations, mostly in the US.

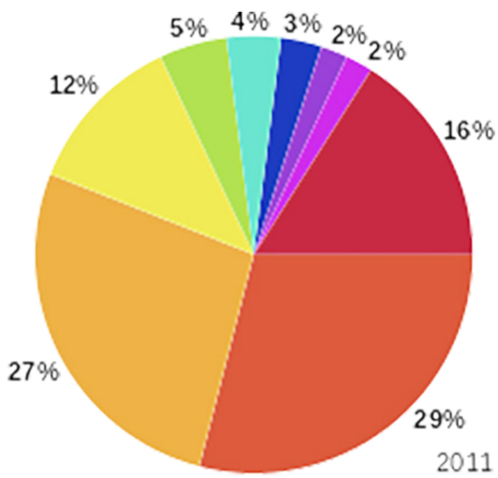
The demand for lithium increased dramatically during the Cold War with the production of nuclear fusion weapons. Both lithium-6 and lithium-7 produce tritium when irradiated by neutrons, and are thus useful for the production of tritium by itself, as well as a form of solid fusion fuel used inside hydrogen bombs in the form of lithium deuteride. The US became the prime producer of lithium between the late 1950s and the mid 1980s. At the end, the stockpile of lithium was roughly 42,000 tonnes of lithium hydroxide. The stockpiled lithium was depleted in lithium-6 by 75%, which was enough to affect the measured atomic weight of lithium in many standardised chemicals, and even the atomic weight of lithium in some "natural sources" of lithium ion which had been "contaminated" by lithium salts discharged from isotope separation facilities, which had found its way into ground water.[36][81]

Lithium was used to decrease the melting temperature of glass and to improve the melting behaviour of aluminium oxide when using the Hall-Héroult process.[82][83] These two uses dominated the market until the middle of the 1990s. After the end of the nuclear arms race, the demand for lithium decreased and the sale of department of energy stockpiles on the open market further reduced prices.[81] In the mid 1990s, several companies started to extract lithium from brine which proved to be a less expensive option than underground or open-pit mining. Most of the mines closed or shifted their focus to other materials because only the ore from zoned pegmatites could be mined for a competitive price. For example, the US mines near Kings Mountain, North Carolina closed before the beginning of the 21st century.

The development of lithium ion batteries increased the demand for lithium and became the dominant use in 2007.[84] With the surge of lithium demand in batteries in the 2000s, new companies have expanded brine extraction efforts to meet the rising demand.[85][86]

It has been argued that lithium will be one of the main objects of geopolitical competition in a world running on renewable energy and dependent on batteries, but this perspective has also been criticised for underestimating the power of economic incentives for expanded production.[87]

Applications



Estimates of global lithium uses in 2011 (picture) and 2015 (numbers below)[116]

- Ceramics and glass (32%)
- Batteries (35%)
- Lubricating greases (9%)
- Continuous casting (5%)
- Air treatment (5%)
- Polymers (4%)
- Primary aluminum production (1%)
- Pharmaceuticals (<1%)
- Other (9%)

Ceramics and glass

Lithium oxide is widely used as a flux for processing silica, reducing the melting point and viscosity of the material and leading to glazes with improved physical properties including low coefficients of thermal expansion. Worldwide, this is one of the largest use for lithium compounds.[116][117] Glazes containing lithium oxides are used for ovenware. Lithium carbonate (Li_2CO3) is generally used in this application because it converts to the oxide upon heating.[118]

Electrical and electronics

Late in the 20th century, lithium became an important component of battery electrolytes and electrodes, because of its high electrode potential. Because of its low atomic mass, it has a high charge- and power-to-weight ratio. A typical lithium-ion battery can generate approximately 3 volts per cell, compared with 2.1 volts for lead-acid and 1.5 volts for zinc-carbon. Lithium-ion batteries, which are rechargeable and have a high energy density, differ from lithium batteries, which are disposable (primary) batteries with lithium or its compounds as the anode.[119][120] Other rechargeable batteries that use lithium include the lithium-ion polymer battery, lithium iron phosphate battery, and the nanowire battery.

Lubricating greases

The third most common use of lithium is in greases. Lithium hydroxide is a strong base and, when heated with a fat, produces a soap made of lithium stearate. Lithium soap has the ability to thicken oils, and it is used to manufacture all-purpose, high-temperature lubricating greases.[15][121][122]

Metallurgy

Lithium (e.g. as lithium carbonate) is used as an additive to continuous casting mould flux slags where it increases fluidity,[123][124] a use which accounts for 5% of global lithium use (2011).[54] Lithium compounds are also used as additives (fluxes) to foundry sand for iron casting to reduce veining.[125]

Lithium (as lithium fluoride) is used as an additive to aluminium smelters (Hall–Héroult process), reducing melting temperature and increasing electrical resistance,[126] a use which accounts for 3% of production (2011).[54]

When used as a flux for welding or soldering, metallic lithium promotes the fusing of metals during the process[127] and eliminates the forming of oxides by absorbing impurities.[128] Alloys of the metal with aluminium, cadmium, copper and manganese are used to make high-performance aircraft parts (see also Lithium-aluminium alloys).[129]

Silicon nano-welding

Lithium has been found effective in assisting the perfection of silicon nano-welds in electronic components for electric batteries and other devices.[130]

Other chemical and industrial uses

Lithium use in flares and pyrotechnics is due to its rose-red flame.[131]

Pyrotechnics

Lithium compounds are used as pyrotechnic colorants and oxidisers in red fireworks and flares.[15][132]

Air purification

Lithium chloride and lithium bromide are hygroscopic and are used as desiccants for gas streams.[15] Lithium hydroxide and lithium peroxide are the salts most used in confined areas, such as aboard spacecraft and submarines, for carbon dioxide removal and air purification. Lithium hydroxide absorbs carbon dioxide from the air by forming lithium carbonate, and is preferred over other alkaline hydroxides for its low weight.

Lithium peroxide (Li_2O_2) in presence of moisture not only reacts with carbon dioxide to form lithium carbonate, but also releases oxygen.[133][134] The reaction is as follows:

$2\ Li_2O2 + 2\ CO_2 \rightarrow 2\ Li_2CO_3 + O_2$.

Some of the aforementioned compounds, as well as lithium perchlorate, are used in oxygen candles that supply submarines with oxygen. These can also include small amounts of boron, magnesium, aluminum, silicon, titanium, manganese, and iron.[135]

Optics

Lithium fluoride, artificially grown as crystal, is clear and transparent and often used in specialist optics for IR, UV and VUV (vacuum UV) applications. It has one of the lowest refractive indexes and the furthest transmission range in the deep UV of most common materials.[136] Finely divided lithium fluoride powder has been used for thermoluminescent radiation dosimetry (TLD): when a sample of such is exposed to radiation, it accumulates crystal defects which, when heated, resolve via a release of bluish light whose intensity is proportional to the absorbed dose, thus allowing this to be quantified.[137] Lithium fluoride is sometimes used in focal lenses of telescopes.[15][138]

The high non-linearity of lithium niobate also makes it useful in non-linear optics applications. It is used extensively in telecommunication products such as mobile phones and optical modulators, for such components as resonant crystals. Lithium applications are used in more than 60% of mobile phones.[139]

Organic and polymer chemistry

Organolithium compounds are widely used in the production of polymer and fine-chemicals. In the polymer industry, which is the dominant consumer of these reagents, alkyl lithium compounds are catalysts/initiators.[140] in anionic polymerization of unfunctionalized olefins.[141][142][143] For the production of fine chemicals, organolithium compounds function as strong bases and as reagents for the formation of carbon-carbon bonds. Organolithium compounds are prepared from lithium metal and alkyl halides.[144]

Many other lithium compounds are used as reagents to prepare organic compounds. Some popular compounds include lithium aluminium hydride ($LiAlH_4$), lithium triethylborohydride, n-butyllithium and tert-butyllithium are commonly used as extremely strong bases called superbases.

Military applications

Metallic lithium and its complex hydrides, such as $Li[AlH_4]$, are used as high-energy additives to rocket propellants.[17] Lithium aluminium hydride can also be used by itself as a solid fuel.[145]

The Mark 50 torpedo stored chemical energy propulsion system (SCEPS) uses a small tank of sulfur hexafluoride gas, which is sprayed over a block of solid lithium. The reaction generates heat, creating steam to propel the torpedo in a closed Rankine cycle.[146]

Lithium hydride containing lithium-6 is used in thermonuclear weapons, where it serves as fuel for the fusion stage of the bomb.[147]

Nuclear

Lithium-6 is valued as a source material for tritium production and as a neutron absorber in nuclear fusion. Natural lithium contains about 7.5% lithium-6 from which large amounts of lithium-6 have been produced by isotope separation for use in nuclear weapons.[148] Lithium-7 gained interest for use in nuclear reactor coolants.[149]

Lithium deuteride was used as fuel in the Castle Bravo nuclear device.

Lithium deuteride was the fusion fuel of choice in early versions of the hydrogen bomb. When bombarded by neutrons, both 6Li and 7Li produce tritium — this reaction, which was not fully understood when hydrogen bombs were first tested, was responsible for the runaway yield of the Castle Bravo nuclear test. Tritium fuses with deuterium in a fusion reaction that is relatively easy to achieve. Although details remain secret, lithium-6 deuteride apparently still plays a role in modern nuclear weapons as a fusion material.[150]

Lithium fluoride, when highly enriched in the lithium-7 isotope, forms the basic constituent of the fluoride salt mixture $LiF\text{-}BeF_2$ used in liquid fluoride nuclear reactors. Lithium fluoride is exceptionally chemically stable and $LiF\text{-}BeF_2$ mixtures have low melting points. In addition, 7Li, Be, and F are among the few nuclides with low enough thermal neutron capture cross-sections not to poison the fission reactions inside a nuclear fission reactor.[note 4][151]

In conceptualised (hypothetical) nuclear fusion power plants, lithium will be used to produce tritium in magnetically confined reactors using deuterium and tritium as the fuel. Naturally occurring tritium is extremely rare, and must be synthetically produced by surrounding the reacting plasma with a 'blanket' containing lithium where neutrons from the deuterium-tritium reaction in the plasma will fission the lithium to produce more tritium:

$^{6}Li + n \rightarrow {}^{4}He + {}^{3}H$.

Lithium is also used as a source for alpha particles, or helium nuclei. When 7Li is bombarded by accelerated protons 8Be is formed, which undergoes fission to form two alpha particles. This feat, called "splitting the atom" at the time, was the first fully man-made nuclear reaction. It was produced by Cockroft and Walton in 1932.[152][153]

In 2013, the US Government Accountability Office said a shortage of lithium-7 critical to the operation of 65 out of 100 American nuclear reactors “places their ability to continue to provide electricity at some risk”. Castle Bravo first used Lithium-7, in the Shrimp, its first device, which weighed only 10 tons, and generated massive nuclear atmospheric contamination of Bikini Atoll. This perhaps accounts for the decline of US nuclear infrastructure.[154] The equipment needed to separate lithium-6 from lithium-7 is mostly a cold war leftover. The US shut down most of this machinery in 1963, when it had a huge surplus of separated lithium, mostly consumed during the twentieth century. The report said it would take five years and $10 million to $12 million to reestablish the ability to separate lithium-6 from lithium-7.[155]

Reactors that use lithium-7 heat water under high pressure and transfer heat through heat exchangers that are prone to corrosion. The reactors use lithium to counteract the corrosive effects of boric acid, which is added to the water to absorb excess neutrons.[155]

Medicine

Lithium is useful in the treatment of bipolar disorder.[156] Lithium salts may also be helpful for related diagnoses, such as schizoaffective disorder and cyclic major depression. The active part of these salts is the lithium ion Li+.[156] They may increase the risk of developing Ebstein's cardiac anomaly in infants born to women who take lithium during the first trimester of pregnancy.[157]

Lithium has also been researched as a possible treatment for cluster headaches.[158]

Biological role

Primary food sources of lithium are grains and vegetables, and, in some areas, drinking water also contains significant amounts.[159] Human intake varies depending on location and diet.

Lithium was first detected in human organs and foetal tissues in the late 19th century. In humans there are no defined lithium deficiency diseases, but low lithium intakes from water supplies were associated with increased rates of suicides, homicides and the arrest rates for drug use and other crimes. The biochemical mechanisms of action of lithium appear to be multifactorial and are intercorrelated with the functions of several enzymes, hormones and vitamins, as well as with growth and transforming factors.

References

^ Weast, Robert (1984). CRC, Handbook of Chemistry and Physics. Boca Raton, Florida: Chemical Rubber Company Publishing. pp. E110. ISBN 0-8493-0464-4.

^ Jump up to:a b Numerical data from: Lodders, Katharina (10 July 2003). "Solar System Abundances and Condensation Temperatures of the Elements" (PDF). The Astrophysical Journal. The American Astronomical Society. 591 (2): 1220–1247. Bibcode:2003ApJ...591.1220L. doi:10.1086/375492. Archived from the original (PDF) on 7 November 2015. Retrieved 1 September 2015. Graphed at File:SolarSystemAbundances.jpg

^ Nuclear Weapon Design. Federation of American Scientists (1998-10-21). fas.org

^ Jump up to:a b c d e f g Krebs, Robert E. (2006). The History and Use of Our Earth's Chemical Elements: A Reference Guide. Westport, Conn.: Greenwood Press. ISBN 978-0-313-33438-2.

^ Huang, Chuanfu; Kresin, Vitaly V. (June 2016). "Note: Contamination-free loading of lithium metal into a nozzle source". Review of Scientific Instruments. 87 (6): 066105. Bibcode:2016RScI...87f6105H. doi:10.1063/1.4953918. ISSN 0034-6748. PMID 27370506.

^ Addison, C. C. (1984). The chemistry of the liquid alkali metals. Chichester [West Sussex]: Wiley. ISBN 978-0471905080. OCLC 10751785.

^ Lide, D. R., ed. (2005). CRC Handbook of Chemistry and Physics (86th ed.). Boca Raton (FL): CRC Press. ISBN 0-8493-0486-5.

^ "The Element Lithium".

^ "Nitrogen, N2, Physical properties, safety, MSDS, enthalpy, material compatibility, gas liquid equilibrium, density, viscosity, inflammability, transport properties". Encyclopedia.airliquide.com. Archived from the original on 21 July 2011. Retrieved 29 September 2010.

^ "Coefficients of Linear Expansion". Engineering Toolbox. Archived from the original on 30 November 2012.

^ Tuoriniemi, Juha; Juntunen-Nurmilaukas, Kirsi; Uusvuori, Johanna; Pentti, Elias; Salmela, Anssi; Sebedash, Alexander (2007). "Superconductivity in lithium below 0.4 millikelvin at ambient pressure". Nature. 447 (7141): 187–9. Bibcode:2007Natur.447..187T. doi:10.1038/nature05820. PMID 17495921. Archived from the original on 25 June 2019. Retrieved 20 April 2018.

^ Struzhkin, V. V.; Eremets, M. I.; Gan, W; Mao, H. K.; Hemley, R. J. (2002). "Superconductivity in dense lithium". Science. 298(5596): 1213–5. Bibcode:2002Sci...298.1213S. doi:10.1126/science.1078535. PMID 12386338.

^ Overhauser, A. W. (1984). "Crystal Structure of Lithium at 4.2 K". Physical Review Letters. 53 (1): 64–65. Bibcode:1984PhRvL..53...64O. doi:10.1103/PhysRevLett.53.64.

^ Schwarz, Ulrich (2004). "Metallic high-pressure modifications of main group elements". Zeitschrift für Kristallographie. 219 (6–2004): 376–390. Bibcode:2004ZK....219..376S. doi:10.1524/zkri.219.6.376.34637.

^ Jump up to:a b c d e f g Hammond, C. R. (2000). The Elements, in Handbook of Chemistry and Physics (81st ed.). CRC press. ISBN 978-0-8493-0481-1.[page needed]

^ SPECIFIC HEAT OF SOLIDS. bradley.edu

^ Jump up to:a b c d e f g Emsley, John (2001). Nature's Building Blocks. Oxford: Oxford University Press. ISBN 978-0-19-850341-5.

^ Jump up to:a b c d Kamienski, Conrad W.; McDonald, Daniel P.; Stark, Marshall W.; Papcun, John R. (2004). "Lithium and lithium compounds". Kirk-Othmer Encyclopedia of Chemical Technology. John Wiley & Sons, Inc. doi:10.1002/0471238961.1209200811011309.a01.pub2. ISBN 978-0471238966.

^ "XXIV.—On chemical analysis by spectrum-observations". Quarterly Journal of the Chemical Society of London. 13 (3): 270. 1861. doi:10.1039/QJ8611300270.

^ Krebs, Robert E. (2006). The history and use of our earth's chemical elements: a reference guide. Greenwood Publishing Group. p. 47. ISBN 978-0-313-33438-2. Archived from the original on 4 August 2016.

^ Institute, American Geological; Union, American Geophysical; Society, Geochemical (1 January 1994). "Geochemistry international". 31 (1–4): 115. Archived from the original on 4 June 2016.

^ Greenwood, Norman N.; Earnshaw, Alan (1984). Chemistry of the Elements. Oxford: Pergamon Press. pp. 97–99. ISBN 978-0-08-022057-4.

^ Beckford, Floyd. "University of Lyon course online (powerpoint) slideshow". Archived from the original on 4 November 2005. Retrieved 27 July 2008. definitions:Slides 8–^ Nichols, Michael A.; Williard, Paul G. (1 February 1993). "Solid-state structures of n-butyllithium-TMEDA, -THF, and -DME complexes". Journal of the American Chemical Society. 115 (4): 1568–1572. doi:10.1021/ja00057a050. ISSN 0002-7863.

^ C., Mehrotra, R. (2009). Organometallic chemistry : a unified approach. [Place of publication not identified]: New Age International Pvt. ISBN 978-8122412581. OCLC 946063142.

^ "Isotopes of Lithium". Berkeley National Laboratory, The Isotopes Project. Archived from the original on 13 May 2008. Retrieved 21 April 2008.

^ File:Binding energy curve - common isotopes.svg shows binding energies of stable nuclides graphically; the source of the data-set is given in the figure background.

^ Sonzogni, Alejandro. "Interactive Chart of Nuclides". National Nuclear Data Center: Brookhaven National Laboratory. Archived from the original on 23 July 2007. Retrieved 6 June2008.

^ Asplund, M.; et al. (2006). "Lithium Isotopic Abundances in Metal-poor Halo Stars". The Astrophysical Journal. 644 (1): 229–259. arXiv:astro-ph/0510636. Bibcode:2006ApJ...644..229A. doi:10.1086/503538.

^ Chaussidon, M.; Robert, F.; McKeegan, K. D. (2006). "Li and B isotopic variations in an Allende CAI: Evidence for the in situ decay of short-lived 10Be and for the possible presence of the short−lived nuclide 7Be in the early solar system" (PDF). Geochimica et Cosmochimica Acta. 70 (1): 224–245. Bibcode:2006GeCoA..70..224C. doi:10.1016/j.gca.2005.08.016. Archived from the original(PDF) on 18 July 2010.

^ Denissenkov, P. A.; Weiss, A. (2000). "Episodic lithium production by extra-mixing in red giants". Astronomy and Astrophysics. 358: L49–L52. arXiv:astro-ph/0005356. Bibcode:2000A&A...358L..49D.

^ Seitz, H. M.; Brey, G. P.; Lahaye, Y.; Durali, S.; Weyer, S. (2004). "Lithium isotopic signatures of peridotite xenoliths and isotopic fractionation at high temperature between olivine and pyroxenes". Chemical Geology. 212 (1–2): 163–177. Bibcode:2004ChGeo.212..163S. doi:10.1016/j.chemgeo.2004.08.009.

^ Duarte, F. J (2009). Tunable Laser Applications. CRC Press. p. 330. ISBN 978-1-4200-6009-6.

^ Jump up to:a b Coplen, T. B.; Bohlke, J. K.; De Bievre, P.; Ding, T.; Holden, N. E.; Hopple, J. A.; Krouse, H. R.; Lamberty, A.; Peiser, H. S.; et al. (2002). "Isotope-abundance variations of selected elements (IUPAC Technical Report)". Pure and Applied Chemistry. 74 (10): 1987. doi:10.1351/pac200274101987.

^ Truscott, Andrew G.; Strecker, Kevin E.; McAlexander, William I.; Partridge, Guthrie B.; Hulet, Randall G. (30 March 2001). "Observation of Fermi Pressure in a Gas of Trapped Atoms". Science. 291 (5513): 2570–2572. Bibcode:2001Sci...291.2570T. doi:10.1126/science.1059318. ISSN 0036-8075. PMID 11283362.

^ "Element Abundances" (PDF). Archived from the original (PDF) on 1 September 2006. Retrieved 17 November 2009.

^ Boesgaard, A. M.; Steigman, G. (1985). "Big bang nucleosynthesis – Theories and observations". Annual Review of Astronomy and Astrophysics. Palo Alto, CA. 23: 319–378. Bibcode:1985ARA&A..23..319B. doi:10.1146/annurev.aa.23.090185.001535. A86-14507 04–90.

^ Woo, Marcus (21 February 2017). "The Cosmic Explosions That Made the Universe". earth. BBC. Archived from the original on 21 February 2017. Retrieved 21 February 2017. A mysterious cosmic factory is producing lithium. Scientists are now getting closer at finding out where it comes from

^ Cain, Fraser (16 August 2006). "Why Old Stars Seem to Lack Lithium". Archived from the original on 4 June 2016.

^ "First Detection of Lithium from an Exploding Star". Archived from the original on 1 August 2015. Retrieved 29 July 2015.

^ Cain, Fraser. "Brown Dwarf". Universe Today. Archived from the original on 25 February 2011. Retrieved 17 November 2009.

^ Reid, Neill (10 March 2002). "L Dwarf Classification". Archived from the original on 21 May 2013. Retrieved 6 March 2013.

^ "Lithium Occurrence". Institute of Ocean Energy, Saga University, Japan. Archived from the original on 2 May 2009. Retrieved 13 March 2009.

^ Jump up to:a b c d "Some Facts about Lithium". ENC Labs. Archivedfrom the original on 10 July 2011. Retrieved 15 October 2010.

^ Schwochau, Klaus (1984). "Extraction of metals from sea water". Inorganic Chemistry. Topics in Current Chemistry. 124. Springer Berlin Heidelberg. pp. 91–133. doi:10.1007/3-540-13534-0_3. ISBN 978-3-540-13534-0.

^ Atkins, Peter (2010). Shriver & Atkins' Inorganic Chemistry(5th ed.). New York: W. H. Freeman and Company. p. 296. ISBN 978-0199236176.

^ "Mindat.org - Mines, Minerals and More". www.mindat.org. Archived from the original on 22 April 2011. Retrieved 4 August 2019.

^ Moores, S. (June 2007). "Between a rock and a salt lake". Industrial Minerals. 477: 58.

^ Taylor, S. R.; McLennan, S. M.; The continental crust: Its composition and evolution, Blackwell Sci. Publ., Oxford, 330 pp. (1985). Cited in Abundances of the elements (data page)

^ Garrett, Donald (2004) Handbook of Lithium and Natural Calcium, Academic Press, cited in The Trouble with Lithium 2 Archived 14 July 2011 at the Wayback Machine, Meridian International Research (2008)

^ Clarke, G.M. and Harben, P.W., "Lithium Availability Wall Map". Published June 2009. Referenced at International Lithium Alliance Archived 20 October 2012 at Archive.today

^ Jump up to:a b c d Lithium Statistics and Information, U.S. Geological Survey, 2018, archived from the original on 3 March 2016, retrieved 25 July 2002

^ Jump up to:a b "The Trouble with Lithium 2" (PDF). Meridian International Research. 2008. Archived (PDF) from the original on 14 July 2011. Retrieved 29 September 2010.

^ Czech Geological Survey (October 2015). Mineral Commodity Summaries of the Czech Republic 2015 (PDF). Prague: Czech Geological Survey. p. 373. ISBN 978-80-7075-904-2. Archived (PDF) from the original on 6 January 2017.

^ "Ore Reserve grows its Finland lithium deposit by 50%". 2019.

^ Risen, James (13 June 2010). "U.S. Identifies Vast Riches of Minerals in Afghanistan". The New York Times. Archivedfrom the original on 17 June 2010. Retrieved 13 June 2010.

^ Page, Jeremy; Evans, Michael (15 June 2010). "Taleban zones mineral riches may rival Saudi Arabia says Pentagon". The Times. London. Archived from the original on 14 May 2011.

^ Morris, Steven (20 January 2017). "Mining firm hopes to extract lithium from Cornwall's hot springs". The Guardian. p. 31.

^ Chassard-Bouchaud, C.; Galle, P.; Escaig, F.; Miyawaki, M. (1984). "Bioaccumulation of lithium by marine organisms in European, American, and Asian coastal zones: microanalytic study using secondary ion emission". Comptes Rendus de l'Académie des Sciences, Série III. 299 (18): 719–24. PMID 6440674.

^ D'Andraba (1800). "Des caractères et des propriétés de plusieurs nouveaux minérauxde Suède et de Norwège, avec quelques observations chimiques faites sur ces substances". Journal de Physique, de Chimie, d'Histoire Naturelle, et des Arts. 51: 239. Archived from the original on 13 July 2015

^ Weeks, Mary (2003). Discovery of the Elements. Whitefish, Montana, United States: Kessinger Publishing. p. 124. ISBN 978-0-7661-3872-8. Retrieved 10 August 2009.

^ Berzelius (1817). "Ein neues mineralisches Alkali und ein neues Metall" [A new mineral alkali and a new metal]. Journal für Chemie und Physik. 21: 44–48. Archived from the original on 3 December 2016. From p. 45: "Herr August Arfwedson, ein junger sehr verdienstvoller Chemiker, der seit einem Jahre in meinem Laboratorie arbeitet, fand bei einer Analyse des Petalits von Uto's Eisengrube, einen alkalischen Bestandtheil, ... Wir haben es Lithion genannt, um dadurch auf seine erste Entdeckung im Mineralreich anzuspielen, da die beiden anderen erst in der organischen Natur entdeckt wurden. Sein Radical wird dann Lithium genannt werden." (Mr. August Arfwedson, a young, very meritorious chemist, who has worked in my laboratory for a year, found during an analysis of petalite from Uto's iron mine, an alkaline component … We've named it lithion, in order to allude thereby to its first discovery in the mineral realm, since the two others were first discovered in organic nature. Its radical will then be named "lithium".)

^ "Johan August Arfwedson". Periodic Table Live!. Archived from the original on 7 October 2010. Retrieved 10 August2009.

^ "Johan Arfwedson". Archived from the original on 5 June 2008. Retrieved 10 August 2009.

^ Jump up to:a b c van der Krogt, Peter. "Lithium". Elementymology & Elements Multidict. Archived from the original on 16 June 2011. Retrieved 5 October 2010.

^ Clark, Jim (2005). "Compounds of the Group 1 Elements". Archived from the original on 11 March 2009. Retrieved 10 August 2009.

^ See:

Arwedson, Aug. (1818) "Undersökning af några vid Utö Jernmalmsbrott förekommende Fossilier, och af ett deri funnet eget Eldfast Alkali" Archived 25 November 2017 at the Wayback Machine, Afhandlingar i Fysik, Kemi och Mineralogi, 6 : 145–172. (in Swedish)

Arwedson, Aug. (1818) "Untersuchung einiger bei der Eisen-Grube von Utö vorkommenden Fossilien und von einem darin gefundenen neuen feuerfesten Alkali"(Investigation of some minerals occurring at the iron mines of Utö and of a new refractory alkali found therein), Journal für Chemie und Physik, 22 (1) : 93–117. (in German)

^ Gmelin, C. G. (1818). "Von dem Lithon" [On lithium]. Annalen der Physik. 59 (7): 238–241. Bibcode:1818AnP....59..229G. doi:10.1002/andp.18180590702. Archived from the original on 9 November 2015. p. 238 Es löste sich in diesem ein Salz auf, das an der Luft zerfloss, und nach Art der Strontiansalze den Alkohol mit einer purpurrothen Flamme brennen machte. (There dissolved in this [solvent; namely, absolute alcohol] a salt that deliquesced in air, and in the manner of strontium salts, caused the alcohol to burn with a purple-red flame.)

^ Jump up to:a b Enghag, Per (2004). Encyclopedia of the Elements: Technical Data – History –Processing – Applications. Wiley. pp. 287–300. ISBN 978-3-527-30666-4.

^ Brande, William Thomas (1821) A Manual of Chemistry, 2nd ed. London, England: John Murray, vol. 2, pp. 57-58.Archived 22 November 2015 at the Wayback Machine

^ Various authors (1818). "The Quarterly journal of science and the arts" (PDF). The Quarterly Journal of Science and the Arts. Royal Institution of Great Britain. 5: 338. Retrieved 5 October 2010.

^ "Timeline science and engineering". DiracDelta Science & Engineering Encyclopedia. Archived from the original on 5 December 2008. Retrieved 18 September 2008.

^ Brande, William Thomas; MacNeven, William James (1821). A manual of chemistry. Long. p. 191. Retrieved 8 October2010.

^ Bunsen, R. (1855). "Darstellung des Lithiums" [Preparation of lithium]. Annalen der Chemie und Pharmacie. 94: 107–111. doi:10.1002/jlac.18550940112. Archived from the original on 6 November 2018. Retrieved 13 August 2015.

^ Green, Thomas (11 June 2006). "Analysis of the Element Lithium". echeat. Archived from the original on 21 April 2012.

^ Garrett, Donald E. (5 April 2004). Handbook of Lithium and Natural Calcium Chloride. p. 99. ISBN 9780080472904. Archived from the original on 3 December 2016.

^ Jump up to:a b Ober, Joyce A. (1994). "Commodity Report 1994: Lithium" (PDF). United States Geological Survey. Archived (PDF) from the original on 9 June 2010. Retrieved 3 November 2010.

^ Deberitz, Jürgen; Boche, Gernot (2003). "Lithium und seine Verbindungen - Industrielle, medizinische und wissenschaftliche Bedeutung". Chemie in Unserer Zeit. 37 (4): 258–266. doi:10.1002/ciuz.200300264.

^ Bauer, Richard (1985). "Lithium - wie es nicht im Lehrbuch steht". Chemie in Unserer Zeit. 19 (5): 167–173. doi:10.1002/ciuz.19850190505.

^ Ober, Joyce A. (1994). "Minerals Yearbook 2007 : Lithium"(PDF). United States Geological Survey. Archived (PDF)from the original on 17 July 2010. Retrieved 3 November 2010.

^ Kogel, Jessica Elzea (2006). "Lithium". Industrial minerals & rocks: commodities, markets, and uses. Littleton, Colo.: Society for Mining, Metallurgy, and Exploration. p. 599. ISBN 978-0-87335-233-8.

^ McKetta, John J. (18 July 2007). Encyclopedia of Chemical Processing and Design: Volume 28 – Lactic Acid to Magnesium Supply-Demand Relationships. M. Dekker. ISBN 978-0-8247-2478-8. Archived from the original on 28 May 2013. Retrieved 29 September 2010.

^ Overland, Indra (1 March 2019). "The geopolitics of renewable energy: Debunking four emerging myths" (PDF). Energy Research & Social Science. 49: 36–40. doi:10.1016/j.erss.2018.10.018. ISSN 2214-6296.

^ Greenwood, Norman N.; Earnshaw, Alan (1997). Chemistry of the Elements (2nd ed.). Butterworth-Heinemann. p. 73. ISBN 978-0-08-037941-8.

^ Jump up to:a b Martin, Richard (8 June 2015). "Quest to Mine Seawater for Lithium Advances". MIT Technology Review. Retrieved 10 February 2016.

^ Ober, Joyce A. "Lithium" (PDF). United States Geological Survey. pp. 77–78. Archived (PDF) from the original on 11 July 2007. Retrieved 19 August 2007.

^ Tarascon, J. M. (2010). "Is lithium the new gold?". Nature Chemistry. 2 (6): 510. Bibcode:2010NatCh...2..510T. doi:10.1038/nchem.680. PMID 20489722.

^ Lithium: The New California Gold Rush Archived 29 July 2017 at the Wayback Machine, Forbes magazine. 2011-10-19

^ Houston, J.; Butcher, A.; Ehren, P.; Evans, K.; Godfrey, L. (2011). "The Evaluation of Brine Prospects and the Requirement for Modifications to Filing Standards" (PDF). Economic Geology. 106 (7): 1225–1239. doi:10.2113/econgeo.106.7.1225. Archived (PDF) from the original on 20 July 2018. Retrieved 28 June 2019.

^ Vikström, H.; Davidsson, S.; Höök, M. (2013). "Lithium availability and future production outlooks". Applied Energy. 110 (10): 252–266. doi:10.1016/j.apenergy.2013.04.005. Archived from the original on 11 October 2017. Retrieved 11 October 2017.

^ Grosjean, P.W.; Medina, P.A.; Keoleian, G.A.; Kesler, S.E.; Everson, M.P; Wallington, T.J. (2011). "Global Lithium Availability: A Constraint for Electric Vehicles?". Journal of Industrial Ecology. 15 (5): 760–775. doi:10.1111/j.1530-9290.2011.00359.x.

^ "8 Top Lithium-producing Countries". Commodity.com. 14 December 2017. Archived from the original on 30 December 2017. Retrieved 14 December 2017.

^ "The Lithium Triangle"http://latintrade.com/the-lithium-triangle/ Archived 10 June 2018 at the Wayback Machine. Latin Trade. Retrieved 2017-8-13.

^ Jump up to:a b Romero, Simon (2 February 2009). "In Bolivia, a Tight Grip on the Next Big Resource". The New York Times. Archivedfrom the original on 1 July 2017.

^ "USGS Mineral Commodities Summaries 2009" (PDF). USGS. Archived (PDF) from the original on 14 June 2010.

^ "Mineral Commodity Summaries 2019" (PDF). U.S. Geological Survey. 2019.

^ Money Game Contributors (26 April 2013). "New Wyoming Lithium Deposit". Business Insider. Archived from the original on 3 May 2013. Retrieved 1 May 2013.

^ Wadia, Cyrus; Albertus, Paul; Srinivasan, Venkat (2011). "Resource constraints on the battery energy storage potential for grid and transportation applications". Journal of Power Sources. 196 (3): 1593–8. Bibcode:2011JPS...196.1593W. doi:10.1016/j.jpowsour.2010.08.056.

^ Gaines, LL.; Nelson, P. (2010). "Lithium-Ion Batteries: Examining Material Demand and Recycling Issues". Argonne National Laboratory. Archived from the original on 3 August 2016. Retrieved 11 June 2016.

^ "University of Michigan and Ford researchers see plentiful lithium resources for electric vehicles". Green Car Congress. 3 August 2011. Archived from the original on 16 September 2011. Retrieved 11 August 2011.

^ "The Precious Mobile Metal". The Financialist. Credit Suisse. 9 June 2014. Archived from the original on 23 February 2016. Retrieved 19 June 2014.

^ "Plateau Energy Metals Peru unit finds large lithium resources". Reuters. 16 July 2018. Archived from the original on 26 July 2018. Retrieved 26 July 2018.

^ "SQM Announces New Lithium Prices – SANTIAGO, Chile". PR Newswire. 30 September 2009. Archived from the original on 30 May 2013. Retrieved 1 May 2013.

^ Jump up to:a b Riseborough, Jesse. "IPad Boom Strains Lithium Supplies After Prices Triple". Bloomberg BusinessWeek. Archived from the original on 22 June 2012. Retrieved 1 May 2013.

^ Cafariello, Joseph (10 March 2014). "Lithium: A Long-Term Investment Buy Lithium!". wealthdaily.com. Archived from the original on 12 June 2018. Retrieved 24 April 2015.

^ Kaskey, Jack (16 July 2014). "Largest Lithium Deal Triggered by Smartphones and Teslas". bloomberg.com. Archivedfrom the original on 12 June 2018. Retrieved 24 April 2015.

^ Marcelo Azevedo, Nicolò Campagnol, Toralf Hagenbruch, Ken Hoffman, Ajay Lala, Oliver Ramsbottom (June 2018). "Lithium and cobalt – a tale of two commodities". McKinsey. p. 9. Retrieved 29 January 2020.

^ Parker, Ann. Mining Geothermal Resources Archived 17 September 2012 at the Wayback Machine. Lawrence Livermore National Laboratory

^ Patel, P. (2011-11-16) Startup to Capture Lithium from Geothermal Plants. technologyreview.com

^ Wald, M. (2011-09-28) Start-Up in California Plans to Capture Lithium, and Market Share Archived 8 April 2017 at the Wayback Machine. The New York Times

^ "How to Invest in Lithium". commodityhq.com. Archivedfrom the original on 11 April 2015. Retrieved 24 April 2015.

^ Jump up to:a b "Lithium" (PDF). 2016. Archived (PDF) from the original on 30 November 2016. Retrieved 29 November 2016 – via US Geological Survey (USGS).

^ Worldwide demand by sector Archived 7 September 2014 at the Wayback Machine

^ Clark, Jim (2005). "Some Compounds of the Group 1 Elements". chemguide.co.uk. Archived from the original on 27 June 2013. Retrieved 8 August 2013.

^ "Disposable Batteries - Choosing between Alkaline and Lithium Disposable Batteries". Batteryreview.org. Archivedfrom the original on 6 January 2014. Retrieved 10 October2013.

^ "Battery Anodes > Batteries & Fuel Cells > Research > The Energy Materials Center at Cornell". Emc2.cornell.edu. Archived from the original on 22 December 2013. Retrieved 10 October 2013.

^ Totten, George E.; Westbrook, Steven R. & Shah, Rajesh J. (2003). Fuels and lubricants handbook: technology, properties, performance, and testing. 1. ASTM International. p. 559. ISBN 978-0-8031-2096-9. Archived from the original on 23 July 2016.

^ Rand, Salvatore J. (2003). Significance of tests for petroleum products. ASTM International. pp. 150–152. ISBN 978-0-8031-2097-6. Archived from the original on 31 July 2016.

^ The Theory and Practice of Mold Fluxes Used in Continuous Casting: A Compilation of Papers on Continuous Casting Fluxes Given at the 61st and 62nd Steelmaking Conference, Iron and Steel Society

^ Lu, Y. Q.; Zhang, G. D.; Jiang, M. F.; Liu, H. X.; Li, T. (2011). "Effects of Li2CO3 on Properties of Mould Flux for High Speed Continuous Casting". Materials Science Forum. 675–677: 877–880. doi:10.4028/www.scientific.net/MSF.675-677.877.

^ "Testing 1-2-3: Eliminating Veining Defects", Modern Casting, July 2014, archived from the original on 2 April 2015, retrieved 15 March 2015

^ Haupin, W. (1987), Mamantov, Gleb; Marassi, Roberto (eds.), "Chemical and Physical Properties of the Hall-Héroult Electrolyte", Molten Salt Chemistry: An Introduction and Selected Applications, Springer, p. 449

^ Garrett, Donald E. (5 April 2004). Handbook of Lithium and Natural Calcium Chloride. Academic Press. p. 200. ISBN

9780080472904. Archived from the original on 3 December 2016.

^ Prasad, N. Eswara; Gokhale, Amol; Wanhill, R. J. H. (20 September 2013). Aluminum-Lithium Alloys: Processing, Properties, and Applications. Butterworth-Heinemann. ISBN 9780124016798.

^ Davis, Joseph R. ASM International. Handbook Committee (1993). Aluminum and aluminum alloys. ASM International. pp. 121–. ISBN 978-0-87170-496-2. Archived from the original on 28 May 2013. Retrieved 16 May 2011.

^ Karki, Khim; Epstein, Eric; Cho, Jeong-Hyun; Jia, Zheng; Li, Teng; Picraux, S. Tom; Wang, Chunsheng; Cumings, John (2012). "Lithium-Assisted Electrochemical Welding in Silicon Nanowire Battery Electrodes" (PDF). Nano Letters. 12 (3): 1392–7. Bibcode:2012NanoL..12.1392K. doi:10.1021/nl204063u. PMID 22339576. Archived(PDF) from the original on 10 August 2017.

^ Koch, Ernst-Christian (2004). "Special Materials in Pyrotechnics: III. Application of Lithium and its Compounds in Energetic Systems". Propellants, Explosives, Pyrotechnics. 29(2): 67–80. doi:10.1002/prep.200400032.

^ Wiberg, Egon; Wiberg, Nils and Holleman, Arnold Frederick (2001) Inorganic chemistry Archived 18 June 2016 at the Wayback Machine, Academic Press. ISBN 0-12-352651-5, p. 1089

^ Mulloth, L.M. & Finn, J.E. (2005). "Air Quality Systems for Related Enclosed Spaces: Spacecraft Air". The Handbook of Environmental Chemistry. 4H. pp. 383–404. doi:10.1007/b107253. ISBN 978-3-540-25019-7.

^ "Application of lithium chemicals for air regeneration of manned spacecraft". Lithium Corporation of America & Aerospace Medical Research Laboratories. 1965. Archivedfrom the original on 7 October 2012.

^ Markowitz, M. M.; Boryta, D. A.; Stewart, Harvey (1964). "Lithium Perchlorate Oxygen Candle. Pyrochemical Source of Pure Oxygen". Industrial & Engineering Chemistry Product Research and Development. 3 (4): 321–30. doi:10.1021/i360012a016.

^ Hobbs, Philip C. D. (2009). Building Electro-Optical Systems: Making It All Work. John Wiley and Sons. p. 149. ISBN 978-0-470-40229-0. Archived from the original on 23 June 2016.

^ Point Defects in Lithium Fluoride Films Induced by Gamma Irradiation. Proceedings of the 7th International Conference on Advanced Technology & Particle Physics: (ICATPP-7): Villa Olmo, Como, Italy. 2001. World Scientific. 2002. p. 819. ISBN 978-981-238-180-4. Archived from the original on 6 June 2016.

^ Sinton, William M. (1962). "Infrared Spectroscopy of Planets and Stars". Applied Optics. 1 (2): 105. Bibcode:1962ApOpt...1..105S. doi:10.1364/AO.1.000105.

^ "You've got the power: the evolution of batteries and the future of fuel cells" (PDF). Toshiba. Archived (PDF) from the original on 17 July 2011. Retrieved 17 May 2009.

^ "Organometallics". IHS Chemicals. February 2012. Archived from the original on 7 July 2012. Retrieved 2 January 2012.

^ Yurkovetskii, A. V.; Kofman, V. L.; Makovetskii, K. L. (2005). "Polymerization of 1,2-dimethylenecyclobutane by organolithium initiators". Russian Chemical Bulletin. 37 (9): 1782–1784. doi:10.1007/BF00962487.

^ Quirk, Roderic P.; Cheng, Pao Luo (1986). "Functionalization of polymeric organolithium compounds. Amination of poly(styryl)lithium". Macromolecules. 19 (5): 1291–1294. Bibcode:1986MaMol..19.1291Q. doi:10.1021/ma00159a001.

^ Stone, F. G. A.; West, Robert (1980). Advances in organometallic chemistry. Academic Press. p. 55. ISBN 978-0-12-031118-7.

^ Bansal, Raj K. (1996). Synthetic approaches in organic chemistry. p. 192. ISBN 978-0-7637-0665-4. Archived from the original on 18 June 2016.

^ "Wayback Machine" (PDF). web.archive.org. 28 June 2003.

^ Hughes, T.G.; Smith, R.B. & Kiely, D.H. (1983). "Stored Chemical Energy Propulsion System for Underwater Applications". Journal of Energy. 7 (2): 128–133. Bibcode:1983JEner...7..128H. doi:10.2514/3.62644.

^ Emsley, John (2011). Nature's Building Blocks.

^ Makhijani, Arjun & Yih, Katherine (2000). Nuclear Wastelands: A Global Guide to Nuclear Weapons Production and Its Health and Environmental Effects. MIT Press. pp. 59–60. ISBN 978-0-262-63204-1. Archived from the original on 13 June 2016.

^ National Research Council (U.S.). Committee on Separations Technology and Transmutation Systems (1996). Nuclear wastes: technologies for separations and transmutation. National Academies Press. p. 278. ISBN 978-0-309-05226-9. Archived from the original on 13 June 2016.

^ Barnaby, Frank (1993). How nuclear weapons spread: nuclear-weapon proliferation in the 1990s. Routledge. p. 39. ISBN 978-0-415-07674-6. Archived from the original on 9 June 2016.

^ Baesjr, C. (1974). "The chemistry and thermodynamics of molten salt reactor fuels". Journal of Nuclear Materials.

51(1): 149–162. Bibcode:1974JNuM...51..149B. doi:10.1016/0022-3115(74)90124-X. OSTI 4470742.

^ Agarwal, Arun (2008). Nobel Prize Winners in Physics. APH Publishing. p. 139. ISBN 978-81-7648-743-6. Archivedfrom the original on 29 June 2016.

^ "'Splitting the Atom': Cockcroft and Walton, 1932: 9. Rays or Particles?" Archived 2 September 2012 at the Wayback Machine Department of Physics, University of Cambridge

^ The Lithium Blues—Or How America Triggered an Out-of-Control Nuke Archived 18 August 2019 at the Wayback Machine[1] Archived 6 June 2019 at the Wayback Machine[2] Archived 18 August 2019 at the Wayback Machine

^ Jump up to:a b Wald, Matthew L. (8 October 2013). "Report Says a Shortage of Nuclear Ingredient Looms". The New York Times. Archived from the original on 1 July 2017.

^ Jump up to:a b Kean, Sam (2011). The Disappearing Spoon.

^ Yacobi S; Ornoy A (2008). "Is lithium a real teratogen? What can we conclude from the prospective versus retrospective studies? A review". Isr J Psychiatry Relat Sci. 45 (2): 95–106. PMID 18982835.

^ Lieb, J.; Zeff (1978). "Lithium treatment of chronic cluster headaches". The British Journal of Psychiatry. 133 (6): 556–558. doi:10.1192/bjp.133.6.556. PMID 737393.

^ Schrauzer, G. N (2002). "Lithium: Occurrence, dietary intakes, nutritional essentiality". Journal of the American College of Nutrition. 21 (1): 14–21. doi:10.1080/07315724.2002.10719188. PMID 11838882.

^ "Lithium 265969". Sigma-Aldrich.

^ Technical data for Lithium Archived 23 March 2015 at the Wayback Machine. periodictable.com

^ Furr, A. K. (2000). CRC handbook of laboratory safety. Boca Raton: CRC Press. pp. 244–246. ISBN 978-0-8493-2523-6.

^ "Illinois Attorney General – Basic Understanding Of Meth". Illinoisattorneygeneral.gov. Archived from the original on 10 September 2010. Retrieved 6 October 2010.

^ Harmon, Aaron R. (2006). "Methamphetamine remediation research act of 2005: Just what the doctor ordered for cleaning up methfields—or sugar pill placebo?" (PDF). North Carolina Journal of Law & Technology. 7. Archived from the original(PDF) on 1 December 2008. Retrieved 5 October 2010.