

## Aluminum

**Discovered:** H.C. Oersted in 1825

**Name:** From *alum*, used by ancient Greeks and Romans as an astringent and as a mordant in dyeing. Sir Humphrey Davy proposed the name aluminum, but changed it to aluminium to have it conform to the spelling of other metals. This spelling was used in the U.S. until 1925 when the ACS went back to the original spelling. The rest of the world uses the “-ium” ending.

**Occurrence:** It is the most common metallic element in the Earth's crust and occurs in many different forms in nature some of which are: bauxite, cryolite ( $\text{Na}_3\text{AlF}_6$ ), micas, feldspars, vermiculite, diaspore ( $\text{AlO}_2\text{H}$ ), gibbsite ( $\text{Al}(\text{OH})_3$ ), garnet ( $\text{Ca}_3\text{Al}_2(\text{SiO}_4)_3$ ), beryl ( $\text{Be}_3\text{Al}_2\text{Si}_6\text{O}_{18}$ ), turquoise ( $\text{Al}_2(\text{OH})_3\text{PO}_4\text{H}_2\text{O}/\text{Cu}$ ), corundum ( $\alpha\text{-Al}_2\text{O}_3$ ), other  $\text{Al}_2\text{O}_3$  with impurities are ruby (Cr(III)), topaz (Fe(III)), sapphire, and oriental emerald.

Bauxite deposits are common. Large reserves are found in Australia, Africa, Brazil, Central America, Guinea, and Jamaica.

**Isolation:** Bauxite ( $\text{AlO}_2\text{H}\cdot n\text{H}_2\text{O}$ ) is dissolved in molten NaOH (1200 °C) and is precipitated with  $\text{CO}_2$ , then dissolved in cryolite at 950 °C and electrolyzed (Bayer process).

**Cost of 1 gram, 1 mole:** \$0.36, \$9.83

**Natural Isotopes:**  $^{27}\text{Al}$  (100%)

<b>Physical and Chemical Properties:</b>	Relatively low melting point
	High electrical conductivity
	Soft
	Low density
	Silvery white in color
	Non-magnetic
	Corrosion resistant
Highly malleable and ductile	

**Reactions:**  $2\text{Al} + 6\text{HCl} \xrightarrow{\Delta} 2\text{AlCl}_3 + 3\text{H}_2$   
 $2\text{Al}(\text{OH})_3 \xrightarrow{\Delta} \text{Al}_2\text{O}_3 + 3\text{H}_2\text{O}$

**Uses:** Alloys for building construction, transportation, containers and packaging, electrical power lines, cookware, etc.

$\text{Al}_8\text{Zr}(\text{OH})_{13}\text{Cl}_3\cdot x\text{H}_2\text{O}$ •glycine is the active ingredient in some antiperspirants

$\text{Al}_2\text{O}_3$  is a major component of Portland cement

## Beryllium

**Discovered:** By L.-N. Vauguelin in 1798 as the oxide, isolated in 1828 by F. Wohler and A.-B. Bussy independently.

**Name:** From *beryl*, the mineral it was originally isolated from ( $\text{Be}_3\text{Al}_2\text{Si}_6\text{O}_{18}$ ). Beryl is derived from the Greek word *beryllous*, which is the precious stone form of beryl. It is also called *glucinium*, from the Greek work *glykys*, for "sweet." (Beryllium compounds tend to have a sweet taste. See note at the bottom of the page.)

**Occurrence:** It is relatively non-abundant in the Earth's crust, concentrated in pegmatite rocks (last part of granite to crystallize). Aquamarine and emerald are precious forms of beryl. Largest deposits are in South America and South Africa.

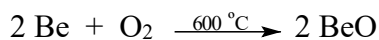
**Isolation:**  $\text{beryl} + \text{Na}_2\text{SiF}_6 \xrightarrow{700^\circ\text{C}} \text{BeF}_2$   
 $\text{BeF}_2 + \text{Mg} \xrightarrow{1300^\circ\text{C}} \text{Be} + \text{MgF}_2$

**Cost for 1 gram, 1 mole:** \$12.30, \$88.45

**Natural Isotopes:**  $^9\text{Be}$  (100%)

**Physical and Chemical Properties:** High melting point  
Grayish white in color  
Soft  
Very low density for a metal  
Relatively non-reactive (e.g. polished Be remains shiny indefinitely)  
Chemically different from other Alkaline Earth metals (e.g. rarely forms ionic compounds; cold, concentrated  $\text{HNO}_3$  deactivates beryllium)

**Reactions:** With only one or two exceptions, the compounds of beryllium are always covalent.



**Uses:** Alloy with copper used in aircraft engines, electronics, and spacecraft  
Alloy with nickel used in high temperature springs and spark-proof equipment  
Moderator in nuclear reactors  
Windows on X-ray tubes

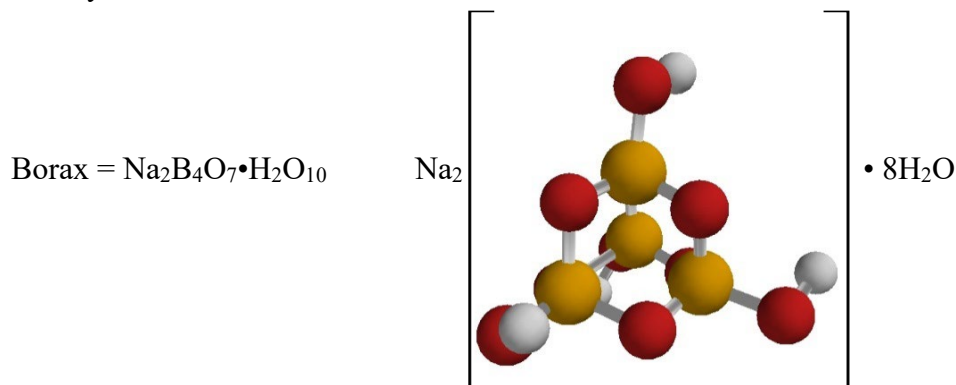
*Note:* Beryllium is very toxic. For example,  $\text{BeCl}_2$  is about 6 times more poisonous than NaCN by weight. Also, the effects may be permanent or may occur years later. For example, skin burns may remain open indefinitely. This is truly nasty stuff. Its toxicity may arise from replacing Mg in some enzymes.

## Boron

**Discovered:** Sir Humphrey Davy, J.L. Gay-Lussac, and L.J. Thenard in 1808

**Name:** *Borax* + Carbon (source + chemical similarity)

**Occurrence:** Although boron is a rare element, in nature it is concentrated in the mineral borax (also called tincal). Large deposits of borax are found in southern California and Turkey.



**Isolation:** i)  $\text{B}_2\text{O}_3 + 3 \text{Mg} \longrightarrow 2 \text{B} + 3 \text{MgO}$  (95-98% pure).  
ii) Electrolytic reduction of fused borates.  
iii) Reduction of volatile boron compounds by  $\text{H}_2$ . (Yields high purity boron: 99.9%)  
iv) Thermal decomposition of  $\text{BX}_3$  and  $\text{B}_n\text{H}_m$ .

**Cost for 1 gram, 1 mole:** \$42.60, \$460

**Natural Isotopes:**  $^{10}\text{B}$  (19.6%)     $^{11}\text{B}$  (80.4%)

**Physical and Chemical Properties:** Very hard  
Low density  
High melting point  
Very low electrical conductivity at room temperature (but good at high temperature)  
Chemically inert at room temperature (except with  $\text{F}_2$ )

**Reactions:**  $2 \text{NaBH}_4 + 2 \text{HCl} \longrightarrow 2 \text{NaCl} + 2 \text{H}_2 + \text{B}_2\text{H}_6$  (diborane)  
 $\text{BCl}_3 + 3 \text{H}_2\text{O} \longrightarrow 3 \text{HCl} + \text{B}(\text{OH})_3$  (boric acid)  
 $\text{BCl}_3 + \text{NH}_3 \xrightarrow{\Delta} (\text{BN})_x$  (artificial diamond)

**Uses:** Pyrotechnic flares (green color)  
Rocket ignitors  
Neutron capture in nuclear reactors ( $^{10}\text{B}$ )  
Antiseptic and fire retardant (boric acid)  
Cleansing flux (borax)  
Borosilicate glass (Pyrex and Kimax, 30-35%)  
Artificial diamonds (BN, boron nitride, 9.3 on Moh's hardness scale)  
Reinforcing materials (boron fiber composites)

## Helium

**Discovered:** In 1868 Pierre Janssen found a new line in the solar spectrum during a solar eclipse. J.N. Lockyer and E. Frankland suggested that it arose from a new element and named it helium. Sir William Ramsey first isolated helium in 1895 from a uranium containing mineral, cleveite. Helium has the distinction of being the only element not discovered on Earth.

**Name:** From the Greek word *helios* (or *ilios*) meaning "the sun" because of the location of its discovery.

**Occurrence:** It is the second most abundant element in the universe, but one of the rarest naturally occurring elements on earth. Its only source here is radioactive decay ( $\alpha$ -particle emission). Earth's gravity is too weak to retain helium so once it breaks into the atmosphere it escapes into space.

**Isolation:** Distilled from natural gas (up to 7% concentration). Most helium is produced in the U.S., with other plants in Poland, India, and the former USSR.

**Cost of 1 gram, 1 mole:** \$0.18, \$0.71

**Natural Isotopes:**  $^3\text{He}$  (trace)       $^4\text{He}$  (100%)

**Physical Properties:** Only known substance that cannot be solidified at atmospheric pressure (even at 0 K,\* it can be solidified at higher pressure)

Only known substance without a triple point.

Has 2 liquid forms. The high temperature form ( $T > 2.2 \text{ K}$ ) behaves as a normal liquid. Below 2.2 K  $\text{HeII}$  exists. Under vacuum,  $\text{HeII}$  evaporates but does not bubble. Forms films only a few hundred atoms thick over all edges in contact with the liquid. The liquid will crawl up vessel walls and out of the container to coat the entire inside of the apparatus. This liquid does not appear to be subject to friction and has zero viscosity and entropy.

Diffuses through many common substances such as glass and rubber making long-term storage difficult.

Colorless, odorless gas

**Uses:** Provides an inert atmosphere  
Refrigerant or cryogenics (33%)  
Flow gas in gas chromatography  
Coolant in some nuclear reactors  
Substitute for  $\text{N}_2$  in synthetic breathing gas for deep-sea diving (reduces chances of developing the bends because of low solubility in the blood)  
Filling balloons

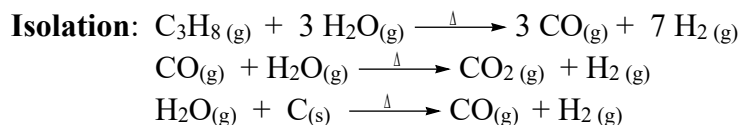
\*The zero-point energy (the energy the molecule possesses at 0 K) is large enough to overcome the intermolecular forces that are necessary for a solid to form.

## Hydrogen

**Discovered:** Paracelsus first characterized it in the late 15<sup>th</sup> century from the reaction between iron and sulfuric acid. Its discovery is credited to Henry Cavendish in 1766, although it had been isolated as early as 1671 by Robert Boyle.

**Name:** From the Greek *hydro* and *genes* meaning "water producer" by Antoine Lavoisier.

**Occurrence:** It is the most abundant element in the universe and is very abundant on Earth (found in water and organic matter).



**Cost of 1 gram, 1 mole:** \$07.5, \$0.15

**Natural Isotopes:** <sup>1</sup>H (99.98%)    <sup>2</sup>H (0.02%)    <sup>3</sup>H (trace)

**Physical and** Colorless, odorless gas

**Chemical** Flammable

**Properties:** Low solubility in most liquid solvents

Lightest of all gases

Becomes metallic(!) at high pressure (> 2 megabars)

**Uses:** Ammonia synthesis (Haber process)

Hydrogenation of fats and oils

Production of HCl

Methanol synthesis

Welding

Filling balloons

Fuel cells will probably constitute a major use in the future

## Lithium

**Discovered:** J.A. Arfvedson in 1817

**Name:** From the Greek *lithos* meaning "stone." This name was chosen to contrast with sodium and potassium which were originally isolated from plant matter. *Note:* Implicit in Arfvedson's choice of name was the observation of the chemical similarity between Li and Na, K. This was 50 years before the periodic table was proposed!

**Occurrence:** It is relatively non-abundant. The most important mineral is spodumene ( $\text{LiAlSi}_2\text{O}_6$ ) with large deposits in the U.S., Canada, Brazil, Argentina, the former USSR, Spain, and Congo.

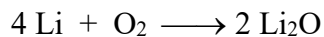
**Isolation:**  $\text{LiAlSi}_2\text{O}_6 \xrightarrow{1100\text{ }^\circ\text{C}} \xrightarrow[250\text{ }^\circ\text{C}]{\text{H}_2\text{SO}_4} \text{Li}_2\text{SO}_4 \xrightarrow{\text{Na}_2\text{CO}_3} \text{Li}_2\text{CO}_3 \xrightarrow{\text{HCl}} 2\text{LiCl}$   
LiCl(55%)/KCl(45%) electrolysis at 450 °C produces Li metal

**Cost for 1 gram, 1 mole:** \$0.95, \$6.65

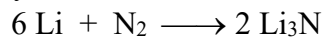
**Natural Isotopes:**  $^6\text{Li}$  (7.4%)       $^7\text{Li}$  (92.6%)

**Physical and Chemical Properties:** Soft (although hardest of the alkali metals)  
Gray in color  
Very low density ( $\sim 0.5\text{ g/cm}^3$ )  
Burns crimson in flame  
Very electropositive  
Soluble in mercury (amalgam) and liquid ammonia  
Reacts directly with most other elements (including  $\text{N}_2$ !)  
Highest elemental oxidation potential

**Reactions:** The only alkali metal that reacts with  $\text{O}_2$  to give the oxide:



The only alkali metal that reacts with  $\text{N}_2$ :



**Uses:** Anode in light weight and long life batteries such as the ones in cell phones and electric cars

Lithium stearate thickens oil into grease (major use)

Alloy with Al used in aircraft construction

Lithium oxide is a component of oven glassware

LiOH used for  $\text{CO}_2$  absorption in submarines/space craft

$\text{Li}_2\text{CO}_3$  is a treatment (Lithobid<sup>®</sup> or Eskalith<sup>®</sup>) for bipolar disorder (manic depression)

LiClO is a bleach for commercial laundries and sanitizing swimming pools

LiCl and LiBr are used as desiccants in air conditioners

## Magnesium

**Discovered:** It was first recognized as an element by Scottish chemist Joseph Black in 1755. Sir Humphrey Davy isolated it in 1808. Compounds were known since ancient times.

**Name:** From the Magnesia district of Thessaly (region of eastern Greece) in which magnesian stone (talc) was found.

**Occurrence:** Common element, usually found as carbonates, sulfates, and silicates because all are water insoluble, minerals: dolomite ( $\text{MgCa}(\text{CO}_3)_2$ ), magnesite ( $\text{MgCO}_3$ ), olivine ( $(\text{MgFe})_2\text{SiO}_4$ ), soapstone (talc,  $\text{Mg}_3\text{Si}_4\text{O}_{10}(\text{OH})_2$ ), asbestos ( $\text{Mg}_3\text{Si}_2\text{O}_5(\text{OH})_4$ ), and micas. Minerals are widespread.

**Isolation:** a) Electrolysis of  $\text{MgCl}_2$  at  $750^\circ\text{C}$



**Cost for 1 gram, 1 mole:** \$0.43, \$10.35

**Natural Isotopes:**  $^{24}\text{Mg}$  (79.0%)     $^{25}\text{Mg}$  (10.0%)     $^{26}\text{Mg}$  (11.0%)

**Physical and Chemical Properties:**

- Low density
- Grayish white in color
- Very electropositive
- Soft
- Oxidation resistant
- Large oxidation potential
- Burns with a bright flame
- Anomalously low melting point

**Reactions:**  $\text{Mg} + \text{N}_2 \xrightarrow{\Delta} \text{Mg}_3\text{N}_2$     Mg actually "burns" in an atmosphere of pure nitrogen.  
Only Li and Mg react directly with  $\text{N}_2$

$2 \text{Mg} + \text{O}_2 \xrightarrow{\Delta} 2 \text{MgO}$     This is the reaction that occurs in a photographic flash bulb.

$\text{MgCl}_2 + 2 \text{NaOH} \xrightarrow{\text{H}_2\text{O}} \text{Mg}(\text{OH})_2 + 2 \text{NaCl}$  (Milk of Magnesia)

Chlorophyll is a magnesium containing compound.

**Uses:** Construction alloys (light weight useful)

- Incendiary bombs
- Antacid ( $\text{Mg}(\text{OH})_2$ , Milk of Magnesia)
- Cathartic ( $\text{MgSO}_4$ , Epsom salts (named after a town in England))
- Grignard reagent

## Neon

**Discovered:** W. Ramsey and M.W. Travers in 1898 isolated neon by the low temperature distillation of air. It was identified by spectroscopic analysis of the sample.

**Name:** From the Greek meaning "new."

**Occurrence:** Relatively rare. Majority of it is found in the atmosphere (*ca.* 1 part in 65,000), but small samples are occluded in igneous rocks. Abundant in the universe.

**Isolation:** From the fractional distillation of air.

**Natural Isotopes:**  $^{20}\text{Ne}$  (91%)     $^{21}\text{Ne}$  (0.26%)     $^{22}\text{Ne}$  (9%)

**Cost for 1 gram, 1 mole:** \$0.68, \$13.75

**Physical and**    Glows red-orange in a vacuum discharge tube.

**Chemical**        Low melting and boiling points.

**Properties:**     Inert, but very limited evidence suggests that it may form a compound with F.

**Uses:** Advertising signs (largest use)

Refrigerant

Lasers

## Sodium

**Discovered:** Sir Humphrey Davy in 1807

**Name:** From the source element soda ( $\text{Na}_2\text{CO}_3$ ), which is found in high content in a plant called *Suwwad* (Arabic). The symbol Na (from *Natrium*) comes from *Neter* (Hebrew) and *Nitrum* (Latin), which were ancient names for basic substances. They became *natron* in 15<sup>th</sup> century Europe.

**Occurrence:** Widespread and plentiful in nature, most common form is NaCl (Utah, Dead Sea, oceans, etc.), also trona ( $\text{Na}_2\text{CO}_3$ ), salt peter ( $\text{NaNO}_3$ ), mirabilite ( $\text{Na}_2\text{SO}_4$ ), borax.

**Isolation:** Electrolysis of NaCl/CaCl<sub>2</sub> (2:3) at 580 °C.

**Cost of 1 gram, 1 mole:** \$0.52, \$11.96

**Natural Isotopes:** <sup>23</sup>Na (100%)

**Physical and Chemical Properties:** Grayish white in color  
Soft  
Burns orange in flame  
Large oxidation potential  
Very electropositive  
Soluble in mercury  
Reacts directly with most elements  
Solutions in liquid NH<sub>3</sub> conduct electricity (Probably by  $\text{Na}^+ + (\text{NH}_3)_x\text{e}^-$ . Dilute solutions are blue and concentrated solns are gold in color.)

**Reactions:**  $2 \text{Na} + \text{O}_2 \longrightarrow \text{Na}_2\text{O}_2$   
 $2 \text{NaOH} + \text{CO}_2 \longrightarrow \text{Na}_2\text{CO}_3 + \text{H}_2\text{O}$  (Soda ash)  
 $\text{NaOH} + \text{xs CO}_2 \longrightarrow \text{NaHCO}_3$  (Baking Soda)  
 $4 \text{Na/Pb} + 4 \text{C}_2\text{H}_5\text{Cl} \longrightarrow \text{Pb}(\text{C}_2\text{H}_5)_4 + 4 \text{NaCl} + 3 \text{Pb}$

**Uses:** Production of  $\text{Pb}(\text{C}_2\text{H}_5)_4$  (anti-knock gasoline additive still used in other countries)  
Heat exchange liquid in fast breeder reactors  
NaOCl is used as a bleach.  
NaHCO<sub>3</sub> is used as baking soda, an antacid, in fire extinguishers, as a cleaning agent, and as toothpaste.  
NaNO<sub>3</sub> is used in fertilizer.

**Note:** One of the primary uses of salt in the diet is in the production of HCl for your stomach. The need for salt was known to the ancients. Roman soldiers were issued salt during campaigns, which is from where the word salary is derived.

## Xenon

**Discovered:** W. Ramsey and M.W. Travers in 1898 by the fractional distillation of air.

**Name:** From the Greek *xenos* meaning "strange(r)."

**Occurrence:** It is 50 parts per billion in the atmosphere.

**Isolation:** From fractional distillation of the air.

**Cost of 1 gram, 1 mole:** \$4.95, \$650

**Natural Isotopes:**  $^{124}\text{Xe}$  (0.1%)  $^{126}\text{Xe}$  (0.1%)  $^{128}\text{Xe}$  (1.9%)  $^{129}\text{Xe}$  (26.4%)  $^{130}\text{Xe}$  (4.1%)  
 $^{131}\text{Xe}$  (21.2%)  $^{132}\text{Xe}$  (26.9%)  $^{134}\text{Xe}$  (10.4%)  $^{136}\text{Xe}$  (8.9%)

**Physical and Chemical Properties:** Glows blue in an electric discharge  
Inert under normal conditions  
Colorless, odorless, and tasteless gases

**Reactions:**  $\text{Xe} + \text{F}_2 \xrightarrow{\Delta} \text{XeF}_x$  (X = 2, 4, or 6)  
 $\text{XeF}_6 + \text{SiO}_2 \longrightarrow \text{XeOF}_4 + \text{XeO}_2\text{F}_2 + \text{XeO}_3$   
 $2 \text{XeF}_2 + 2 \text{H}_2\text{O} \longrightarrow 2 \text{Xe} + 4 \text{HF} + \text{O}_2$

**Uses:** Manufacture of electron tubes, stroboscopic lamps, bactericidal lamps, and used to excite ruby lasers for generating coherent light  
Bubble chambers and probes in the atomic energy field  
Automobile and truck headlights  
Nuclear reaction moderator