

# Boron

From Wikipedia, the free encyclopedia

**Boron** (English pronunciation: /ˈbɔːrɒn/) is the chemical element with atomic number 5 and the chemical symbol **B**. Boron is a metalloid. Because boron is not produced by stellar nucleosynthesis, it is a low-abundance element in both the solar system and the Earth's crust. However, boron is concentrated on Earth by the water-solubility of its more common naturally-occurring compounds, the borate minerals. These are mined industrially as evaporate ores, such as borax and kernite.

Chemically uncombined boron is not found naturally on Earth. Industrially, very pure isolated boron is produced with difficulty, as boron tends to form refractory materials containing small amounts of carbon or other elements. Several allotropes of boron exist: amorphous boron is a brown powder and crystalline boron is black, extremely hard (about 9.5 on Mohs' scale), and a poor conductor at room temperature. Elemental boron is used as a dopant in the semiconductor industry.

The major industrial scale uses of boron compounds are in sodium perborate bleaches, and the borax component of fiberglass insulation. Boron polymers and ceramics play specialized roles as high-strength lightweight structural and refractory materials. Boron compounds are used in silica-based glasses and ceramics to give them resistance to thermal shock. Boron-containing reagents are used for the synthesis of organic compounds, as intermediate in the synthesis of fine chemicals. A few boron-containing organic pharmaceuticals are used, or are in study. Natural boron is composed of two stable isotopes, one of which (boron-10) has a number of uses as a neutron-capturing agent.

In biology, borates have low toxicity in mammals (similar to table salt), but are more toxic to arthropods and are used as insecticides. Boric acid is mildly antimicrobial, and a natural boron-containing organic antibiotic is known. Boron is essential to life. Small amounts of boron compounds play a strengthening role in the cell walls of all plants, making boron necessary in soils. Experiments indicate a role for boron as an ultratrace element in animals, but the nature of its role in animal physiology is unknown.

## Contents

- 1 History and etymology
- 2 Characteristics
  - 2.1 Allotropes
  - 2.2 Chemistry of the element
    - 2.2.1 Chemical compounds
      - 2.2.1.1 Organoboron chemistry
      - 2.2.1.2 Compounds of B(I) and B(II)
  - 2.3 Isotopes
    - 2.3.1 Commercial isotope enrichment
    - 2.3.2 Enriched boron (boron-10)
    - 2.3.3 Depleted boron (boron-11)
    - 2.3.4 NMR spectroscopy
  - 2.4 Occurrence
- 3 Production
  - 3.1 Market trend
- 4 Applications
  - 4.1 Glass and ceramics
  - 4.2 Detergent formulations and bleaching agents
  - 4.3 Insecticides

beryllium ← <b>boron</b> → carbon						
-	<span style="font-size: 2em;">s</span> <b>B</b> <span style="font-size: 2em;">□</span>					
↑						
<b>B</b>						Periodic table
↓						
Al						
<b>Appearance</b>						
black-brown						
						
<b>General properties</b>						
<b>Name, symbol, number</b>	boron, B, 5					
<b>Pronunciation</b>	<span><span>/<span><span>ˈ</span><span>b</span><span>ɔːr</span><span>ɒ</span><span>n</span></span>/</span></span>					
<b>Element category</b>	metalloid					
<b>Group, period, block</b>	13, 2, p					
<b>Standard atomic weight</b>	10.811(7)					
<b>Electron configuration</b>	<span>[</span> He <span>]</span> 2s <sup>2</sup> 2p <sup>1</sup>					
<b>Electrons per shell</b>	2, 3 (Image)					
<b>Physical properties</b>						
<b>Phase</b>	solid					
<b>Liquid density at m.p.</b>	2.08 g·cm <sup>-3</sup>					
<b>Melting point</b>	2349 K, 2076 °C, 3769 °F					
<b>Boiling point</b>	4200 K, 3927 °C, 7101 °F					
<b>Heat of fusion</b>	50.2 kJ·mol <sup>-1</sup>					
<b>Heat of vaporization</b>	480 kJ·mol <sup>-1</sup>					
<b>Molar heat capacity</b>	11.087 J·mol <sup>-1</sup> ·K <sup>-1</sup>					
<b>Vapor pressure</b>						
P (Pa)	1	10	100	1 k	10 k	100 k
at T (K)	2348	2562	2822	3141	3545	4072
<b>Atomic properties</b>						
<b>Oxidation states</b>	3, 2, 1 <sup>[1]</sup> (mildly acidic oxide)					
<b>Electronegativity</b>	2.04 (Pauling scale)					

- 4.4 Semiconductors
- 4.5 Magnets
- 4.6 High-hardness and abrasive compounds
  - 4.6.1 Boron carbide
  - 4.6.2 Other superhard boron compounds
- 4.7 Shielding in nuclear reactors
- 4.8 Other nonmedical uses
- 4.9 Research areas
- 5 Biological role
  - 5.1 Analytical quantification
- 6 Boron pharmaceuticals and biologicals
  - 6.1 Health issues
- 7 See also
- 8 References
- 9 External links

## History and etymology

The name boron originates from the Arabic word *بورق* *buraq* or the Persian word *بور* *burah*,<sup>[6]</sup> which are names for the mineral borax.<sup>[7]</sup>



Sassolite

Boron compounds were known thousands of years ago. Borax was known from the deserts of western Tibet, where it received the name of *tincal*, derived from the Sanskrit. Borax glazes were used in China from AD300, and some tincal even reached the West, where the Arabic alchemist Jābir ibn Hayyān seems to mention it in 700. Marco Polo brought some glazes back to Italy in the 13th century. Agricola, around 1600, reports the use of borax as a flux in metallurgy. In 1777, boric acid was recognized in the hot springs (soffioni) near Florence, Italy, and

became known as *sal sedativum*, with mainly medical uses. The rare mineral is called sassolite, which is found at Sasso, Italy. Sasso was the main source of European borax from 1827 to 1872, at which date American sources replaced it.<sup>[8][9]</sup>

Boron was not recognized as an element until it was isolated by Sir Humphry Davy<sup>[10]</sup> and by Joseph Louis Gay-Lussac and Louis Jacques Thénard<sup>[11]</sup> In 1808 Davy observed that electric current sent through a solution of borates produced a brown precipitate on one of the electrodes. In his subsequent experiments he used potassium to reduce boric acid instead of electrolysis. He produced enough boron to confirm a new element and named the element *boracium*.<sup>[10]</sup> Gay-Lussac and Thénard use iron to reduce boric acid at high temperatures. They showed by oxidizing boron with air that boric acid is a oxidation product of boron.<sup>[11][12]</sup> Jöns Jakob Berzelius identified boron as an element in 1824.<sup>[13]</sup> Pure boron was arguably first produced by the American chemist Ezekiel Weintraub in 1909.<sup>[14][15][16]</sup>

## Characteristics

### Allotropes

*Main article: Allotropes of boron*

Boron is similar to carbon in its capability to form stable covalently bonded molecular networks. Even nominally disordered (amorphous) boron contains regular boron icosahedra which are, however, bonded randomly to each other without long-range order.<sup>[17][18]</sup> Crystalline boron is a very hard, black material with a high melting point of above 2000 °C. It exists in four major polymorphs: *α*, *β*, *γ* and *T*. Whereas *α*, *β* and *T* phases are based on B<sub>12</sub> icosahedra, the *γ*-phase can be described as a rocksalt-type arrangement of the icosahedra and B<sub>2</sub> atomic pairs.<sup>[19]</sup> It can be produced by compressing other boron phases to 12–20 GPa and heating to 1500–1800 °C; it remains stable after releasing the temperature and pressure. The *T* phase is

**Ionization energies** 1st: 800.6 kJ·mol<sup>−1</sup>  
**(more)** 2nd: 2427.1 kJ·mol<sup>−1</sup>  
 3rd: 3659.7 kJ·mol<sup>−1</sup>

<b>Atomic radius</b>	90 <span> </span> pm				
<b>Covalent radius</b>	84±3 <span> </span> pm				
<b>Van der Waals radius</b>	192 <span> </span> pm				
<b>Miscellanea</b>					
<b>Magnetic ordering</b>	diamagnetic <sup>[2]</sup>				
<b>Electrical resistivity</b>	(20 <span> </span> °C) ~10 <sup>6</sup> <span> </span> Ω·m				
<b>Thermal conductivity</b>	27.4 <span> </span> W·m <sup>−1</sup> ·K <sup>−1</sup>				
<b>Thermal expansion</b>	(25 <span> </span> °C) ( <i>β</i> form) 5–7 <sup>[3]</sup> μm·m <sup>−1</sup> ·K <sup>−1</sup>				
<b>Speed of sound (thin rod)</b>	(20 <span> </span> °C) 16,200 <span> </span> m·s <sup>−1</sup>				
<b>Mohs hardness</b>	~9.5				
<b>CAS registry number</b>	7440-42-8				
<b>Most stable isotopes</b>					
Main article: Isotopes of boron					
<b>iso</b>	<b>NA</b>	<b>half-life</b>	<b>DM</b>	<b>DE (MeV)</b>	<b>DP</b>
<sup>10</sup> B	19.9(7)%*	<sup>10</sup> B is stable with 5 neutrons <sup>[4]</sup>			
<sup>11</sup> B	80.1(7)%*	<sup>11</sup> B is stable with 6 neutrons <sup>[4]</sup>			
*Boron-10 content may be as low as 19.1% and as high as 20.3% in natural samples. Boron-11 is the remainder in such cases. <sup>[5]</sup>					



Boron chunks

produced at similar pressures, but higher temperatures of 1800–2200 °C. As to the  $\alpha$  and  $\beta$  phases, they might both coexist at ambient conditions with the  $\beta$  phase being more stable.<sup>[19][20][21]</sup> Compressing boron above 160 GPa produces a boron phase with an as yet unknown structure, and this phase is a superconductor at temperatures 6–12 K.<sup>[22]</sup>

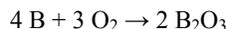
Boron phase	$\alpha$	$\beta$	$\gamma$	T
Symmetry	Rhombohedral	Rhombohedral	Orthorhombic	Tetragonal
Atoms/unit cell <sup>[19]</sup>	12	~105	28	
Density (g/cm <sup>3</sup> ) <sup>[23][24][25][26]</sup>	2.46	2.35	2.52	2.36
Vickers hardness (GPa) <sup>[27][28]</sup>	42	45	50–58	
Bulk modulus (GPa) <sup>[28][29]</sup>	185	224	227	
Bandgap (eV) <sup>[28][30]</sup>	2	1.6	2.1	

## Chemistry of the element

*See also Category:* Boron compounds.

Elemental boron is rare and poorly studied because the material is extremely difficult to prepare. Most studies on "boron" involve samples that contain small amounts of carbon. Chemically, boron behaves more closely to silicon than to aluminium. Crystalline boron is chemically inert and resistant to attack by boiling hydrofluoric or hydrochloric acid. When finely divided, it is attacked slowly by hot concentrated hydrogen peroxide, hot concentrated nitric acid, hot sulfuric acid or hot mixture of sulfuric and chromic acids.<sup>[15][31]</sup>

The rate of oxidation of boron depends upon the crystallinity, particle size, purity and temperature. Boron does not react with air at room temperature, but at higher temperatures it burns to form boron trioxide:



Boron undergoes halogenation to give trihalides, for example:



These trihalides in practice are usually made from the oxides.

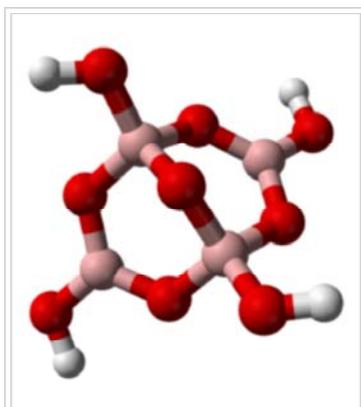
### Chemical compounds

In its most familiar compounds, boron has the formal oxidation state III. These include oxides, sulfides, nitrides, and halides.

The trihalides adopt a planar trigonal structure. These compounds are Lewis acids in that they readily form adducts with electron-pair donors, which are called Lewis bases. For example, fluoride (F<sup>−</sup>) and boron trifluoride (BF<sub>3</sub>) combined to give the tetrafluoroborate anion, BF<sub>4</sub><sup>−</sup>. Boron trifluoride is used in the petrochemical industry as a catalyst. The halides react with water to form boric acid.

Boron is found in nature on Earth entirely as various oxides of B(III), often associated with other elements. The more than one hundred borates all feature boron in oxidation state +3. These mineral resemble silicates in some respect, although boron is often found not only in a tetrahedral coordination with oxygen, but also in a trigonal planar configuration. Unlike silicates, the boron minerals never feature boron with coordination number greater than four. A typical motif is exemplified by the tetraborate anions of the common mineral borax, shown at left. The formal negative charge of the tetrahedral borate centers is balanced by metal cations in the minerals, such as the sodium (Na<sup>+</sup>) in borax.

The boron nitrides are notable for the variety of structures that they adopt. They adopt structures analogous to various allotropes of carbon, including graphite, diamond, and nanotubes. In the diamond-like structure called cubic boron nitride (trade name Borazon), boron atoms exist in the tetrahedral structure of carbons atoms in diamond, but one in every



Ball-and-stick model of tetraborate anion,  $[\text{B}_4\text{O}_5(\text{OH})_4]^{2-}$ , as it occurs in crystalline borax,  $\text{Na}_2[\text{B}_4\text{O}_5(\text{OH})_4] \cdot 8\text{H}_2\text{O}$ . Boron atoms are pink, with bridging oxygens in red, and four hydroxyl hydrogens in white. Note two borons are trigonally bonded  $\text{sp}^2$  with no formal charge, while the other two borons are tetrahedrally bonded  $\text{sp}^3$ , each carrying a formal charge of  $-1$ . The oxidation state of all borons is III. This mixture of boron coordination numbers and formal charges is characteristic of natural boron minerals.

four B-N bonds can be viewed as a coordinate covalent bond, wherein two electrons are donated by the nitrogen atom which acts as the Lewis base to a bond to the Lewis acidic boron(III) centre. Cubic boron nitride, among other applications, is used as an abrasive, as it has a hardness comparable with diamond (the two substances are able to produce scratches on each other). In the BN compound analogues of graphite, the positively charged boron and negatively charged nitrogen atoms in each plane lie adjacent to the oppositely charged atom in the next plane, consequently graphic and hexagonal boron nitride have very different properties.

#### Organoboron chemistry

*Main article: Organoboron chemistry*

A large number of organoboron compounds are known and many are useful in organic synthesis. Organoboron(III) compounds are usually tetrahedral or trigonal planar, for example, tetraphenylborate ( $\text{B}(\text{C}_6\text{H}_5)_4^-$ ) vs triphenylborane ( $\text{B}(\text{C}_6\text{H}_5)_3$ ). Many are produced from hydroboration, which employs diborane ( $\text{B}_2\text{H}_6$ ).

#### Compounds of B(I) and B(II)

Boron forms a variety of stable compounds with formal oxidation state less than three. As for many covalent compound, oxidation states are often of little meaning in boron hydrides and metal borides. The halides also form derivatives of B(I) and B(II). BF, isoelectronic with  $\text{N}_2$ , is not isolable in condensed form, but  $\text{B}_2\text{F}_4$  and  $\text{B}_4\text{Cl}_4$  are well characterized. [32]

Binary metal-boron compounds, the metal borides, feature boron in oxidation state less than III. Illustrative is magnesium diboride ( $\text{MgB}_2$ ). In this material, the boron centers are trigonal planar, forming sheets akin to the carbon in graphite. Each boron has a formal  $-1$  charge and magnesium is assigned a formal charge of  $2+$ . In 2001 this material was

found to be a high-temperature superconductor.

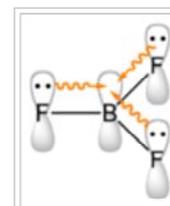
Other borides find specialized applications as hard materials for cutting tools.

From the structural perspective, the most distinctive chemical compounds of boron are the hydrides. Included in this series are the cluster compounds dodecaborate ( $\text{B}_{12}\text{H}_{12}^{2-}$ ), decaborane ( $\text{B}_{10}\text{H}_{14}$ ), and the carboranes such as  $\text{C}_2\text{B}_{10}\text{H}_{12}$ . Characteristically such compounds feature boron with coordination numbers greater than four.

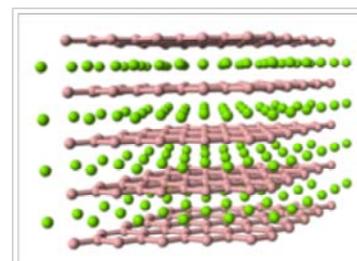
## Isotopes

*Main article: Isotopes of boron*

Boron has two naturally occurring and stable isotopes,  $^{11}\text{B}$  (80.1%) and  $^{10}\text{B}$  (19.9%). The mass difference results in a wide range of  $\delta^{11}\text{B}$  values, which are defined as a fractional difference between the  $^{11}\text{B}$  and  $^{10}\text{B}$  and traditionally expressed in parts per thousand, in natural waters ranging from  $-16$  to  $+59$ . There are 13 known isotopes of boron, the shortest-lived isotope is  $^7\text{B}$  which decays through proton emission and alpha decay. It has a half-life of  $3.5 \times 10^{-22}$  s. Isotopic fractionation of boron is controlled by the exchange reactions of the boron species  $\text{B}(\text{OH})_3$  and  $[\text{B}(\text{OH})_4]^-$ . Boron isotopes are also fractionated during mineral crystallization, during  $\text{H}_2\text{O}$  phase changes in hydrothermal systems, and during hydrothermal alteration of rock. The latter effect results in preferential removal of the  $^{10}\text{B}(\text{OH})_4$  ion onto clays. It results in solutions enriched in  $^{11}\text{B}(\text{OH})_3$  and therefore may be responsible for the large  $^{11}\text{B}$  enrichment in seawater relative to both oceanic crust and continental crust; this difference may act as an isotopic signature. [33] The exotic  $^{17}\text{B}$  exhibits a nuclear halo, i.e. its radius is appreciably larger than that predicted by the liquid drop model. [34]



Boron (III) trifluoride structure, showing "empty" boron p orbital in pi-type coordinate covalent bonds



Ball-and-stick model of superconductor magnesium diboride. Boron atoms lie in hexagonal aromatic graphite-like layers, with a charge of  $-1$  per boron. Magnesium (II) ions lie between layers

The <sup>10</sup>B isotope is good at capturing thermal neutrons. Natural boron is about 20% <sup>10</sup>B and 80% <sup>11</sup>B. The nuclear industry enriches natural boron to nearly pure <sup>10</sup>B. The less-valuable by-product, depleted boron, is nearly pure <sup>11</sup>B.

### Commercial isotope enrichment

Because of its high neutron cross-section, boron-10 is often used to control fission in nuclear reactors as a neutron-capturing substance.<sup>[35]</sup> Several industrial-scale enrichment processes have been developed, however only the fractionated vacuum distillation of the dimethyl ether adduct of boron trifluoride (DME-BF<sub>3</sub>) and column chromatography of borates are being used.<sup>[36][37]</sup>

### Enriched boron (boron-10)

Enriched boron or <sup>10</sup>B is used in both radiation shielding and in boron neutron capture therapy. In the latter, a compound containing <sup>10</sup>B is attached to a muscle near a tumor. The patient is then treated with a relatively low dose of thermal neutrons. This causes energetic and short range alpha radiation from the boron to bombard the tumor.<sup>[38][39][40][41]</sup>

In nuclear reactors, <sup>10</sup>B is used for reactivity control and in emergency shutdown systems. It can serve either function in the form of borosilicate control rods or as boric acid. In pressurized water reactors, boric acid is added to the reactor coolant when the plant is shut down for refueling. It is then slowly filtered out over many months as fissile material is used up and the fuel becomes less reactive.<sup>[42]</sup>

In future manned interplanetary spacecraft, <sup>10</sup>B has a theoretical role as structural material (as boron fibers or BN nanotube material) which would also serve a special role in the radiation shield. One of the difficulties in dealing with cosmic rays, which are mostly high energy protons, is that some secondary radiation from interaction of cosmic rays and spacecraft materials is high energy spallation neutrons. Such neutrons can be moderated by materials high in light elements such as polyethylene, but the moderated neutrons continue to be a radiation hazard unless actively absorbed in the shielding. Among light elements that absorb thermal neutrons, <sup>6</sup>Li and <sup>10</sup>B appear as potential spacecraft structural materials which serve both for mechanical reinforcement and radiation protection.<sup>[43]</sup>

### Depleted boron (boron-11)

Cosmic radiation will produce secondary neutrons if it hits spacecraft structures. Those neutrons will be captured in <sup>10</sup>B, if it is present in the spacecraft's semiconductors, producing a gamma ray, an alpha particle, and a lithium ion. These resultant decay products may then irradiate nearby semiconductor 'chip' structures, causing data loss (bit flipping, or single event upset). In radiation hardened semiconductor designs, one countermeasure is to use **depleted boron** which is greatly enriched in <sup>11</sup>B and contains almost no <sup>10</sup>B. <sup>11</sup>B is largely immune to radiation damage. Depleted boron is a by-product of the nuclear industry.<sup>[42]</sup>

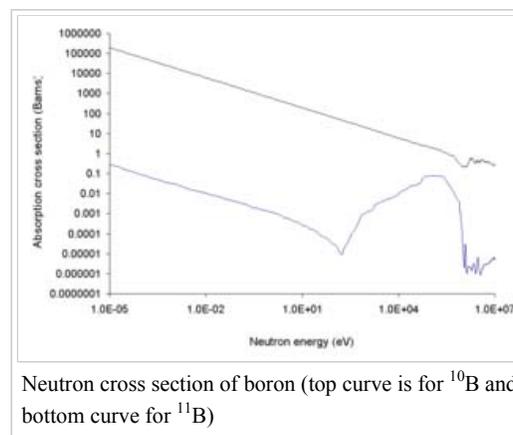
<sup>11</sup>B is also a candidate as a fuel for aneutronic fusion. When struck by a proton with energy of about 500 keV, it produces three alpha particles and 8.7 MeV of energy. Most other fusion reactions involving hydrogen and helium produce penetrating neutron radiation, which weakens reactor structures and induces long term radioactivity thereby endangering operating personnel. Whereas, the alpha particles from <sup>11</sup>B fusion can be turned directly into electric power, and all radiation stops as soon as the reactor is turned off.<sup>[44]</sup>

### NMR spectroscopy

Both <sup>10</sup>B and <sup>11</sup>B possess nuclear spin. The nuclear spin of <sup>10</sup>B is 3 and that of <sup>11</sup>B is 3/2. These isotopes are, therefore, of use in nuclear magnetic resonance spectroscopy; and spectrometers specially adapted to detecting the boron-11 nuclei are available commercially. The <sup>10</sup>B and <sup>11</sup>B nuclei also cause splitting in the resonances of attached nuclei.<sup>[45]</sup>

### Occurrence

*See also Category:* Borate minerals.





A fragment of ulexite

Boron is a relatively rare element in the Earth's crust, representing only 0.001%. The worldwide commercial borate deposits are estimated at 10 million tonnes.<sup>[46][47]</sup> Turkey and the United States are the world's largest producers of boron.<sup>[48][49]</sup> Turkey has almost 72% of the world's boron reserves.<sup>[50]</sup> Boron does not appear on Earth in elemental form but is found combined in borax, boric acid, colemanite, kernite, ulexite and borates. Boric acid is sometimes found in volcanic spring waters.



Borax crystals

Ulexite is one of over a hundred borate minerals; it is a fibrous crystal where individual fibers can guide light like optical fibers.<sup>[51]</sup>

Economically important sources of boron are rasorite (kernite) and tincal (borax ore). They are both found in the Mojave Desert of California, but the largest borax deposits are in Central and Western Turkey including the provinces of Eskişehir, Kütahya and Balıkesir.<sup>[52][53][54]</sup>

## Production

The production of boron compounds does not involve formation of elemental boron, but exploits the convenient availability of borates.

The earliest routes to elemental boron involved reduction of boric oxide with metals such as magnesium or aluminium. However the product is almost always contaminated with metal borides. Pure boron can be prepared by reducing volatile boron halides with hydrogen at high temperatures. Ultrapure boron, for the use in semiconductor industry, is produced by the decomposition of diborane at high temperatures and then further purified with the zone melting or Czochralski processes.<sup>[55]</sup>

## Market trend

Estimated global consumption of boron rose to a record 1.8 million tonnes of B<sub>2</sub>O<sub>3</sub> in 2005, following a period of strong growth in demand from Asia, Europe and North America. Boron mining and refining capacities are considered to be adequate to meet expected levels of growth through the next decade.

The form in which boron is consumed has changed in recent years. The use of ores like colemanite has declined following concerns over arsenic content. Consumers have moved towards the use of refined borates and boric acid that have a lower pollutant content. The average cost of crystalline boron is \$5/g.<sup>[56]</sup>

Increasing demand for boric acid has led a number of producers to invest in additional capacity. Eti Mine Company of Turkey opened a new boric acid plant with the production capacity of 100,000 tonnes per year at Emet in 2003. Rio Tinto Group increased the capacity of its boron plant from 260,000 tonnes per year in 2003 to 310,000 tonnes per year by May 2005, with plans to grow this to 366,000 tonnes per year in 2006. Chinese boron producers have been unable to meet rapidly growing demand for high quality borates. This has led to imports of sodium tetraborate (borax) growing by a hundredfold between 2000 and 2005 and boric acid imports increasing by 28% per year over the same period.<sup>[57][58]</sup>

The rise in global demand has been driven by high growth rates in fiberglass and borosilicate production. A rapid increase in the manufacture of reinforcement-grade fiberglass in Asia with a consequent increase in demand for borates has offset the development of boron-free reinforcement-grade fiberglass in Europe and the USA. The recent rises in energy prices may lead to greater use of insulation-grade fiberglass, with consequent growth in the boron consumption. Roskill Consulting Group forecasts that world demand for boron will grow by 3.4% per year to reach 21 million tonnes by 2010. The highest growth in demand is expected to be in Asia where demand could rise by an average 5.7% per year.<sup>[57][59]</sup>

## Applications

Nearly all boron ore extracted from the Earth is destined for refinement into boric acid and sodium tetraborate pentahydrate. In the United States, 70% of the boron is used for the production of glass and ceramics.<sup>[60][61]</sup>

### Glass and ceramics

Borosilicate glass, which is typically 12–15% B<sub>2</sub>O<sub>3</sub>, 80% SiO<sub>2</sub>, and 2% Al<sub>2</sub>O<sub>3</sub>, has a low coefficient of thermal expansion giving it a good resistance to thermal shock. Duran and Pyrex are two major brand names for this glass, used both in laboratory glassware and in consumer cookware and bakeware, chiefly for this resistance.<sup>[62]</sup>

Boron filaments are high-strength, lightweight materials that are used chiefly for advanced aerospace structures as a component of composite materials, as well as limited production consumer and sporting goods such as golf clubs and fishing rods.<sup>[63][64]</sup> The fibers can be produced by chemical vapor deposition of boron on a tungsten filament.<sup>[48][65]</sup>

Boron fibers and sub-millimeter sized crystalline boron springs are produced by laser-assisted chemical vapor deposition. Translation of the focused laser beam allows to produce even complex helical structures. Such structures show good mechanical properties (elastic modulus 450 GPa, fracture strain 3.7%, fracture stress 17 GPa) and can be applied as reinforcement of ceramics or in micromechanical systems.<sup>[66]</sup>

### Detergent formulations and bleaching agents

Borax is used in various household laundry and cleaning products,<sup>[67]</sup> including the well-known "20 Mule Team Borax" laundry booster and "Boraxo" powdered hand soap. It is also present in some tooth bleaching formulas.<sup>[61]</sup>

Sodium perborate serves as a source of active oxygen in many detergents, laundry detergents, cleaning products, and laundry bleaches. However, despite its name, "Borateem" laundry bleach no longer contains any boron compounds, using sodium percarbonate instead as a bleaching agent.

### Insecticides

Boric acid is used as an insecticide, notably against ants, fleas, and cockroaches.<sup>[68]</sup>

### Semiconductors

Boron is a useful dopant for such semiconductors as silicon, germanium, and silicon carbide. Having one fewer valence electron than the host atom, it donates a hole resulting in p-type conductivity. Traditional method of introducing boron into semiconductors is via its atomic diffusion at high temperatures. This process uses either solid (B<sub>2</sub>O<sub>3</sub>), liquid (BBr<sub>3</sub>), or gaseous boron sources (B<sub>2</sub>H<sub>6</sub> or BF<sub>3</sub>). However, after 1970s, it was mostly replaced by ion implantation, which relies mostly on BF<sub>3</sub> as a boron source.<sup>[69]</sup> Boron trichloride gas is also an important chemical in semiconductor industry, however not for doping but rather for plasma etching of metals and their oxides.<sup>[70]</sup> Triethylborane is also injected into vapor deposition reactors as a boron source. Examples are the plasma deposition of boron-containing hard carbon films, silicon nitride-boron nitride films, and for doping of diamond film with boron.<sup>[71]</sup>

### Magnets

Boron is a component of neodymium magnets (Nd<sub>2</sub>Fe<sub>14</sub>B), which are the strongest type of permanent magnet. They are found in a variety of domestic and professional electromechanical and electronic devices, such as magnetic resonance imaging (MRI), various motors and actuators, computer HDDs, CD and DVD players, mobile phones, timer switches, speakers, and so on.<sup>[2]</sup>

### High-hardness and abrasive compounds

*Main article: Superhard materials*

Several boron compounds are known for their extreme hardness and toughness.

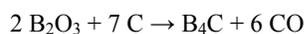
Boron carbide and cubic boron nitride powders are widely used as abrasives. Metal borides are used for coating tools through chemical vapor deposition or physical vapor deposition. Implantation of boron ions into metals and alloys, through ion implantation or ion beam deposition, results in a spectacular increase in surface resistance and microhardness. Laser alloying has also been successfully used for the same purpose. These borides are an alternative to diamond coated tools, and their (treated) surfaces have similar properties to those of the bulk boride.<sup>[72]</sup>

### Boron carbide



Borosilicate glassware. Displayed are two beakers and a test tube.

Boron carbide is a ceramic material which is obtained by decomposing  $B_2O_3$  with carbon in the electric furnace:



Boron carbide's structure is only approximately  $B_4C$ , and it shows a clear depletion of carbon from this suggested stoichiometric ratio. This is due to its very complex structure. The substance can be seen with empirical formula  $B_{12}C_3$  (i.e., with  $B_{12}$  dodecahedra being a motif), but with less carbon as the suggested  $C_3$  units are replaced with B-C chains, and there are smaller ( $B_6$ ) octahedra present as well. (See the article for structural analysis).

The repeating polymer plus semi-crystalline structure of boron carbide gives it great structural strength per weight. It is used in tank armor, bulletproof vests, and numerous other structural applications.

Boron carbide's ability to absorb neutrons without forming long-lived radionuclides (especially when doped with extra boron-10) makes the material attractive as an absorbent for neutron radiation arising in nuclear power plants. Nuclear applications of boron carbide include shielding, control rods and shut-down pellets. Within control rods, boron carbide is often powdered, to increase its surface area.<sup>[73]</sup>

### Other superhard boron compounds

Mechanical properties of BCN solids<sup>[74]</sup> and  $ReB_2$ <sup>[75]</sup>

Material	Diamond	cubic- $BC_2N$	cubic- $BC_5$	cubic-BN	$B_4C$	$ReB_2$
Vickers hardness (GPa)	115	76	71	62	38	22
Fracture toughness ( $MPa\ m^{1/2}$ )	5.3	4.5	9.5	6.8	3.5	

- Heterodiamond (also called BCN);
- Boron nitride. This material is isoelectronic to carbon. Similar to carbon, it has both hexagonal (soft graphite-like h-BN) and cubic (hard, diamond-like c-BN) forms. h-BN is used as a high temperature component and lubricant. c-BN, also known under commercial name borazon,<sup>[76]</sup> is a superior abrasive. Its hardness is only slightly smaller, but chemical stability is superior to that of diamond.
- Rhenium diboride can be produced at ambient pressures, but is rather expensive because of rhenium. The hardness of  $ReB_2$  exhibits considerable anisotropy because of its hexagonal layered structure. Its value is comparable to that of tungsten carbide, silicon carbide, titanium diboride or zirconium diboride.<sup>[75]</sup>
- $AlMgB_{14} + TiB_2$  composites possess high hardness and wear resistance and are used in either bulk form or as coatings for components exposed to high temperatures and wear loads.<sup>[77]</sup>

### Shielding in nuclear reactors

Boron shielding is used as a control for nuclear reactors, taking advantage of its high cross-section for neutron capture.

### Other nonmedical uses



Boron-containing emergency flare

Because of its distinctive green flame, amorphous boron is used in pyrotechnic flares.<sup>[78]</sup>\*Starch and casein-based adhesives contain sodium tetraborate decahydrate ( $Na_2B_4O_7 \cdot 10 H_2O$ )

Some anti-corrosion systems contain borax.<sup>[79]</sup> Sodium borates are used as a flux for soldering silver and gold and with ammonium chloride for welding ferrous metals.<sup>[80]</sup> They are also fire retarding additives to plastics and rubber articles.<sup>[81]</sup>

Boric acid (also known as orthoboric acid)  $H_3BO_3$  is used in the production of textile fiberglass and flat panel displays<sup>[61][82]</sup> and in many PVAc and PVOH

based adhesives.

- Triethylborane is a substance which ignites the JP-7 fuel of the Pratt & Whitney J58 turbojet/ramjet engines powering the Lockheed SR-71 Blackbird.<sup>[83]</sup> It was also used to ignite the F-1 Engines on the Saturn V Rocket utilized by NASA's Apollo and Skylab programs from 1967 until 1973. Triethylborane is suitable for this because of



Boron carbide is used for inner plates of ballistic vests



Launch of *Apollo 15* Saturn V rocket, using triethylborane ignitor

its pyrophoric properties, especially the fact that it burns with a very high temperature.<sup>[84]</sup> Triethylborane is an industrial initiator in radical reactions, where it is effective even at low temperatures.

## Research areas

Magnesium diboride is an important superconducting material with the transition temperature of 39 K. MgB<sub>2</sub> wires are produced with the powder-in-tube process and applied in superconducting magnets.<sup>[85][86]</sup>

Amorphous boron is used as a melting point depressant in nickel-chromium braze alloys.<sup>[87]</sup>

## Biological role

There is a boron-containing natural antibiotic, boromycin, isolated from streptomyces.<sup>[88][89]</sup> Boron is an essential plant nutrient, required primarily for maintaining the integrity of cell walls. Conversely, high soil concentrations of > 1.0 ppm can cause marginal and tip necrosis in leaves as well as poor overall growth performance. Levels as low as 0.8 ppm can cause these same symptoms to appear in plants particularly sensitive to boron in the soil. Nearly all plants, even those somewhat tolerant of boron in the soil, will show at least some symptoms of boron toxicity when boron content in the soil is greater than 1.8 ppm. When this content exceeds 2.0 ppm, few plants will perform well and some may not survive. When boron levels in plant tissue exceed 200 ppm symptoms of boron toxicity are likely to appear.<sup>[90][91][92]</sup>

As an ultratrace element, boron is necessary for the optimal health of rats, although it is necessary in such small amounts that ultrapurified foods and dust filtration of air is necessary to induce boron deficiency, which manifest as poor coat or hair quality. Presumably, boron is necessary to other mammals. No deficiency syndrome in humans has been described. Small amounts of boron occur widely in the diet, and the amounts needed in the diet would, by analogy with rodent studies, be very small. The exact physiological role of boron in the animal kingdom is poorly understood.<sup>[93]</sup>

Boron occurs in all foods produced from plants. Since 1989 its nutritional value has been argued. It is thought that boron plays several biochemical roles in animals, including humans.<sup>[94]</sup> The U.S. Department of agriculture conducted an experiment in which postmenopausal women took 3 mg of boron a day. The results showed that supplemental boron reduced excretion of calcium by 44%, and activated estrogen and vitamin D, suggesting a possible role in the suppression of osteoporosis. However, whether these effects were conventionally nutritional, or medicinal, could not be determined. The US National Institutes of Health quotes this source:

Total daily boron intake in normal human diets ranges from 2.1–4.3 mg boron/day.<sup>[95][96]</sup>

## Analytical quantification

For determination of boron content in food or materials the colorimetric curcumin method is used. Boron has to be transferred to boric acid or borates and on reaction with curcumin in acidic solution, a red colored boron-chelate complex, rosocyanine, is formed.<sup>[97]</sup>

## Boron pharmaceuticals and biologicals

Boric acid has antiseptic, antifungal, and antiviral properties and for this reasons is applied as a water clarifier in swimming pool water treatment.<sup>[98]</sup> Mild solutions of boric acid have been used as eye antiseptics.

A number of potential boronated pharmaceuticals using boron-10, have been prepared for use in boron neutron capture therapy (BNCT).<sup>[99]</sup>

Some boron compounds show promise in treating arthritis, though none have as yet been generally approved for the purpose.<sup>[100]</sup>

Boron is used as an intermediate in pharmaceutical synthesis, but it appeared as an active element in its first-approved organic pharmaceutical in bortezomib, a new class of drug called proteasome inhibitors, which are active in myeloma and one form of lymphoma. The boron atom in bortezomib binds the catalytic site of the 26S proteasome<sup>[101]</sup> with high affinity and specificity.

## Health issues

Elemental boron and borates are non-toxic to humans and animals (approximately similar to table salt). The LD<sub>50</sub> (dose at which there is 50% mortality) for animals is about 6 g per kg of body weight. Substances with LD<sub>50</sub> above 2 g are considered non-toxic. The minimum lethal dose for humans has not been established, but an intake of 4 g/day was reported without incidents, and medical dosages of 20 g of boric acid for neutron capture therapy caused no problems. Fish have survived for 30 min in a saturated boric acid solution and can survive longer in strong borax solutions.<sup>[102]</sup> Boric acid is more toxic to insects than to mammals, and is routinely used as an insecticide.<sup>[68]</sup>

The boranes and similar gaseous compounds are quite poisonous. As usual, it is not an element that is intrinsically poisonous, but toxicity depends on structure.<sup>[8][9]</sup>

The boranes (boron hydrogen compounds) are toxic as well as highly flammable and require special care when handling. Sodium borohydride presents a fire hazard due to its reducing nature, and the liberation of hydrogen on contact with acid. Boron halides are corrosive.<sup>[103]</sup>

Congenital endothelial dystrophy type 2, a rare form of corneal dystrophy, is linked to mutations in SLC4A11 gene that encodes a transporter reportedly regulating the intracellular concentration of boron.<sup>[104]</sup>

## See also

- Allotropes of boron
- Category: Boron compounds
- Boron deficiency
- Boron oxide
- Boron nitride
- Boron neutron capture therapy
- Boronic acid
- Hydroboration-oxidation reaction
- Suzuki coupling

## References

1. <sup>^</sup> Zhang, K.Q.; Guo, B.; Braun, V.; Dulick, M.; Bernath, P.F. (1995). "Infrared Emission Spectroscopy of BF and AlF" (<http://bernath.uwaterloo.ca/media/125.pdf>) . *J. Molecular Spectroscopy* **170**: 82. doi:10.1006/jmsp.1995.1058 (<http://dx.doi.org/10.1006%2Fjmsp.1995.1058>) . <http://bernath.uwaterloo.ca/media/125.pdf>.
2. <sup>^ a b</sup> Lide, David R. (ed.) (2000). *Magnetic susceptibility of the elements and inorganic compounds, in Handbook of Chemistry and Physics* ([http://www-d0.fnal.gov/hardware/cal/lvps\\_info/engineering/elementmagn.pdf](http://www-d0.fnal.gov/hardware/cal/lvps_info/engineering/elementmagn.pdf)) . CRC press. ISBN 0849304814. [http://www-d0.fnal.gov/hardware/cal/lvps\\_info/engineering/elementmagn.pdf](http://www-d0.fnal.gov/hardware/cal/lvps_info/engineering/elementmagn.pdf).
3. <sup>^</sup> Holcombe Jr., C. E.; Smith, D. D.; Lorc, J. D.; Duerlesen, W. K.; Carpenter, D. A. (October 1973). "Physical-Chemical Properties of beta -Rhombohedral Boron". *High Temp. Sci.* **5** (5): 349-57.
4. <sup>^ a b</sup> "Atomic Weights and Isotopic Compositions for All Elements" ([http://physics.nist.gov/cgi-bin/Compositions/stand\\_alone.pl](http://physics.nist.gov/cgi-bin/Compositions/stand_alone.pl)) . National Institute of Standards and Technology. [http://physics.nist.gov/cgi-bin/Compositions/stand\\_alone.pl](http://physics.nist.gov/cgi-bin/Compositions/stand_alone.pl). Retrieved 2008-09-21.
5. <sup>^</sup> Szegedi, S.; Várad, M.; Buczkó, Cs. M.; Várnagy, M.; Sztaricskai, T. (1990). "Determination of boron in glass by neutron transmission method". *Journal of Radioanalytical and Nuclear Chemistry Letters* **146**: 177. doi:10.1007/BF02165219 (<http://dx.doi.org/10.1007%2FBF02165219>) .
6. <sup>^</sup> Shipley, Joseph T. (2001). *The Origins of English Words: A Discursive Dictionary of Indo-European Roots* (<http://books.google.com/?id=m1UKpE4YEK&pg=PA83>) . JHU Press. ISBN 9780801867842. <http://books.google.com/?id=m1UKpE4YEK&pg=PA83>.
7. <sup>^</sup> "Etymology of Elements" (<http://www.innvista.com/science/chemistry/elements/etymolo.htm>) . innvista. <http://www.innvista.com/science/chemistry/elements/etymolo.htm>. Retrieved 2009-06-06.
8. <sup>^ a b</sup> Garrett, Donald E. (1998). *Borates: handbook of deposits, processing, properties, and use*. Academic Press. pp. 102;385–386. ISBN 0122760603.
9. <sup>^ a b</sup> "Boron" (<http://mysite.du.edu/~jcalvert/phys/boron.htm>) . <http://mysite.du.edu/~jcalvert/phys/boron.htm>. Retrieved 2009-05-05.
10. <sup>^ a b</sup> Davy H (1809). "An account of some new analytical researches on the nature of certain bodies, particularly the alkalies, phosphorus, sulphur, carbonaceous matter, and the acids hitherto undecomposed: with some general observations on chemical theory" (<http://books.google.com/books?id=gpwEAAAAYAAJ&pg=PA140#v=onepage&q&f=false>) . *Philosophical Transactions of the Royal Society of London* **99**: 33–104. <http://books.google.com/books?id=gpwEAAAAYAAJ&pg=PA140#v=onepage&q&f=false>.
11. <sup>^ a b</sup> Gay Lussac, J.L. and Thenard, L.J. (1808) "Sur la décomposition et la recomposition de l'acide boracique," (<http://books.google.com/books?id=e6Aw616K5ysC&pg=PA169#v=onepage&q&f=false>) *Annales de chimie* [later: *Annales de chimie et de physique*], vol. 68, pp. 169–174.
12. <sup>^</sup> Weeks, Mary Elvira (1933). "XII. Other Elements Isolated with the Aid of Potassium and Sodium: Beryllium, Boron, Silicon and Aluminum" (<http://books.google.com/books?id=SJK9BPdNWcC&pg=PA156>) . *The Discovery of the Elements*. Easton, PA: Journal of Chemical Education. p. 156. ISBN 0-7661-3872-0. <http://books.google.com/books?id=SJK9BPdNWcC&pg=PA156>.
13. <sup>^</sup> Berzelius produced boron by reducing a borofluoride salt; specifically, by heating potassium borofluoride with potassium metal. See: Berzelius, J. (1824) "Undersökning af flusspatssyran och dess märkvärdigaste föreningar" (<http://books.google.com/books/>)

- id=pJIPAAAAYAAJ&pg=PA46#v=onepage&q&f=false) (Part 2) (Investigation of hydrofluoric acid and of its most noteworthy compounds), *Kongliga Vetenskaps-Academiens Handlingar* (Proceedings of the Royal Science Academy), vol. 12, pp. 46-98; see especially pp. 88ff. Reprinted in German as: Berzelius, J. J. (1824) "Untersuchungen über die Flußspathsäure und deren merkwürdigste Verbindungen" (<http://gallica.bnf.fr/ark:/12148/bpt6k150878/f123.image.f=Annalen%20der%20Physic.langEN>), Pogendorff's *Annalen der Physik und Chemie*, vol. 78, pages 113-150.
14. ^ Weintraub Ezekiel (1909). "Preparation and properties of pure boron". *Transactions of the American Electrochemical Society* **16**: 165–184.
  15. ^ a b Laubengayer, A. W.; Hurd, D. T.; Newkirk, A. E.; Hoard, J. L. (1943). "Boron. I. Preparation and Properties of Pure Crystalline Boron". *Journal of the American Chemical Society* **65** (10): 1924–1931. doi:10.1021/ja01250a036 (<http://dx.doi.org/10.1021%2Fja01250a036>).
  16. ^ Borchert, W.; Dietz, W.; Koelker, H. (1970). "Crystal Growth of Beta-Rhombohedral Boron" ([http://www.osti.gov/energycitations/product.biblio.jsp?osti\\_id=4098583](http://www.osti.gov/energycitations/product.biblio.jsp?osti_id=4098583)). *Zeitschrift für Angewandte Physik* **29**: 277. [http://www.osti.gov/energycitations/product.biblio.jsp?osti\\_id=4098583](http://www.osti.gov/energycitations/product.biblio.jsp?osti_id=4098583).
  17. ^ Delaplane, R.G.; Dahlborg, U; Graneli, B; Fischer, P; Lundstrom, T (1988). "A neutron diffraction study of amorphous boron". *Journal of Non-Crystalline Solids* **104** (2–3): 249. doi:10.1016/0022-3093(88)90395-X (<http://dx.doi.org/10.1016%2F0022-3093%2888%2990395-X>).
  18. ^ R.G. Delaplane; Dahlborg, U; Howells, W; Lundstrom, T (1988). "A neutron diffraction study of amorphous boron using a pulsed source". *Journal of Non-Crystalline Solids* **106**: 66. doi:10.1016/0022-3093(88)90229-3 (<http://dx.doi.org/10.1016%2F0022-3093%2888%2990229-3>).
  19. ^ a b c Oganov A.R., Chen J., Gatti C., Ma Y.-M., Yu T., Liu Z., Glass C.W., Ma Y.-Z., Kurakevych O.O., Solozhenko V.L. (2009). "Ionic high-pressure form of elemental boron" (<http://mysbfiles.stonybrook.edu/~aoganov/files/Boron-Nature-2009.pdf>). *Nature* **457** (7231): 863–867. doi:10.1038/nature07736 (<http://dx.doi.org/10.1038%2Fnature07736>). PMID 19182772 (<http://www.ncbi.nlm.nih.gov/pubmed/19182772>). <http://mysbfiles.stonybrook.edu/~aoganov/files/Boron-Nature-2009.pdf>.
  20. ^ van Setten M.J., Uijtewaal M.A., de Wijs G.A., de Groot R.A. (2007). "Thermodynamic stability of boron: The role of defects and zero point motion". *J. Am. Chem. Soc.* **129** (9): 2458–2465. doi:10.1021/ja0631246 (<http://dx.doi.org/10.1021%2Fja0631246>). PMID 17295480 (<http://www.ncbi.nlm.nih.gov/pubmed/17295480>).
  21. ^ Widom M., Mihalkovic M. (2008). "Symmetry-broken crystal structure of elemental boron at low temperature". *Phys. Rev. B* **77** (6): 064113. doi:10.1103/PhysRevB.77.064113 (<http://dx.doi.org/10.1103%2FPhysRevB.77.064113>).
  22. ^ Eremets, M. I.; Struzhkin, VV; Mao, H; Hemley, RJ (2001). "Superconductivity in Boron". *Science* **293** (5528): 272. doi:10.1126/science.1062286 (<http://dx.doi.org/10.1126%2Fscience.1062286>). PMID 11452118 (<http://www.ncbi.nlm.nih.gov/pubmed/11452118>).
  23. ^ Wentorf Jr, R. H. (1965). "Boron: Another Form" (<http://www.sciencemag.org/cgi/content/abstract/147/3653/49>). *Science* **147** (3653): 49–50 (Powder Diffraction File database (CAS number 7440–42–8)). doi:10.1126/science.147.3653.49 (<http://dx.doi.org/10.1126%2Fscience.147.3653.49>). PMID 17799779 (<http://www.ncbi.nlm.nih.gov/pubmed/17799779>). <http://www.sciencemag.org/cgi/content/abstract/147/3653/49>.
  24. ^ Hoard, J. L.; Sullenger, D. B.; Kennard, C. H. L.; Hughes, R. E. (1970). "The structure analysis of β-rhombohedral boron". *J. Solid State Chem.* **1** (2): 268–277. doi:10.1016/0022-4596(70)90022-8 (<http://dx.doi.org/10.1016%2F0022-4596%2870%2990022-8>).
  25. ^ Will, G.; Kiefer, B. (2001). "Electron Deformation Density in Rhombohedral α-Boron". *Zeitschrift für anorganische und allgemeine Chemie* **627** (9): 2100. doi:10.1002/1521-3749(200109)627:9<2100::AID-ZAAC2100>3.0.CO;2-G (<http://dx.doi.org/10.1002%2F1521-3749%28200109%29627%3A9%3C2100%3A%3AAID-ZAAC2100%3E3.0.CO%3B2-G>).
  26. ^ Talley, C. P.; LaPlaca, S.; Post, B. (1960). "A new polymorph of boron". *Acta Crystallogr.* **13** (3): 271. doi:10.1107/S0365110X60000613 (<http://dx.doi.org/10.1107%2FS0365110X60000613>).
  27. ^ Solozhenko, V. L.; Kurakevych, O. O.; Oganov, A. R. (2008). "On the hardness of a new boron phase, orthorhombic γ-B<sub>28</sub>". *Journal of Superhard Materials* **30** (6): 428–429. doi:10.3103/S1063457608060117 (<http://dx.doi.org/10.3103%2FS1063457608060117>).
  28. ^ a b c Zarechnaya, E. Yu.; Dubrovinsky, L.; Dubrovinskaja, N.; Filinchuk, Y.; Chernyshov, D.; Dmitriev, V.; Miyajima, N.; El Goresy, A. et al. (2009). "Superhard Semiconducting Optically Transparent High Pressure Phase of Boron". *Phys. Rev. Lett.* **102** (18): 185501. Bibcode 2009PhRvL.102r5501Z (<http://adsabs.harvard.edu/abs/2009PhRvL.102r5501Z>). doi:10.1103/PhysRevLett.102.185501 (<http://dx.doi.org/10.1103%2FPhysRevLett.102.185501>). PMID 19518885 (<http://www.ncbi.nlm.nih.gov/pubmed/19518885>).
  29. ^ Nelmes, R. J.; Loveday, J. S.; Allan, D. R.; Hull, S.; Hamel, G.; Grima, P.; Hull, S. (1993). "Neutron- and x-ray-diffraction measurements of the bulk modulus of boron". *Phys. Rev. B* **47** (13): 7668. doi:10.1103/PhysRevB.47.7668 (<http://dx.doi.org/10.1103%2FPhysRevB.47.7668>).
  30. ^ ed. Madelung, O. (1983). *Landolt-Bornstein, New Series*. **17e**. Springer-Verlag, Berlin.
  31. ^ "WebElements.com – Boron" (<http://www.webelements.com/boron/>). <http://www.webelements.com/boron/>. Retrieved 2009-05-05.
  32. ^ Greenwood, Norman N.; Earnshaw, Alan. (1997), *Chemistry of the Elements* (2nd ed.), Oxford: Butterworth-Heinemann, ISBN 0080379419
  33. ^ Barth, S. (1997). "Boron isotopic analysis of natural fresh and saline waters by negative thermal ionization mass spectrometry". *Chemical Geology* **143** (3–4): 255–261. doi:10.1016/S0009-2541(97)00107-1 (<http://dx.doi.org/10.1016%2FS0009-2541%2897%2900107-1>).
  34. ^ Liu, Z. (2003). "Two-body and three-body halo nuclei". *Science in China G: Physics Mechanics and Astronomy* **46** (4): 441. doi:10.1360/03yw0027 (<http://dx.doi.org/10.1360%2F03yw0027>).
  35. ^ "Results of the B4C Control Rod Test QUENCH-07" (<http://bibliothek.fzk.de/zb/berichte/FZKA6746.pdf>).
  36. ^ "Commissioning of Boron Enrichment Plant" (<http://library.igcar.gov.in/html/Contents/IGCNewsletter/nl48/A2.htm>). Indira Gandhi Centre for Atomic Research. <http://library.igcar.gov.in/html/Contents/IGCNewsletter/nl48/A2.htm>. Retrieved 2008-09-21.
  37. ^ see Aida, Masao; Fujii, Yasuhiko; Okamoto, Makoto (1986). "Chromatographic Enrichment of 10B by Using Weak-Base Anion-Exchange Resin". *Separation Science and Technology* **21** (6): 643–654. doi:10.1080/01496398608056140 (<http://dx.doi.org/10.1080%2F01496398608056140>). showing an enrichment from 18% to above 94%.
  38. ^ Barth, Rolf F. (2003). "A Critical Assessment of Boron Neutron Capture Therapy: An Overview". *Journal of Neuro-Oncology* **62** (1): 1–5. doi:10.1023/A:1023262817500 (<http://dx.doi.org/10.1023%2FA%3A1023262817500>).

39. <sup>^</sup> Coderre, Jeffrey A.; Morris, GM (1999). "The Radiation Biology of Boron Neutron Capture Therapy". *Radiation Research* **151** (1): 1–18. doi:10.2307/3579742 (http://dx.doi.org/10.2307%2F3579742) . JSTOR 3579742 (http://www.jstor.org/stable/3579742) . PMID 9973079 (http://www.ncbi.nlm.nih.gov/pubmed/9973079) .
40. <sup>^</sup> Barth, Rolf F.; S; F (15 February 1990). "Boron Neutron Capture Therapy of Cancer" (http://cancerres.aacrjournals.org/cgi/content/citation/50/4/1061) . *Cancer Research* **50** (4): 1061–1070. PMID 2404588 (http://www.ncbi.nlm.nih.gov/pubmed/2404588) . http://cancerres.aacrjournals.org/cgi/content/citation/50/4/1061.
41. <sup>^</sup> http://www.pharmainfo.net/reviews/boron-neutron-capture-therapy-overview
42. <sup>^ a b</sup> Duderstadt, James J.; Hamilton, Louis J. (1976). *Nuclear Reactor Analysis*. Wiley-Interscience. p. 245. ISBN 0471223638.
43. <sup>^</sup> Doering, R.; Nishi Y. (2007). *Handbook of semiconductor manufacturing technology*. CRC Press. pp. 31–39. ISBN 1574446754.
44. <sup>^</sup> Nevins, W. M. (1998). "A Review of Confinement Requirements for Advanced Fuels". *Journal of Fusion Energy* **17** (1): 25–32. doi:10.1023/A:1022513215080 (http://dx.doi.org/10.1023%2FA%3A1022513215080) .
45. <sup>^</sup> "Boron NMR" (http://rmn.iqfr.csic.es/guide/eNMR/chem/B.html) . BRUKER Biospin. http://rmn.iqfr.csic.es/guide/eNMR/chem/B.html. Retrieved 2009-05-05.
46. <sup>^</sup> Argust, Peter (1998). "Distribution of boron in the environment". *Biological Trace Element Research* **66** (1–3): 131–143. doi:10.1007/BF02783133 (http://dx.doi.org/10.1007%2FBF02783133) . PMID 10050915 (http://www.ncbi.nlm.nih.gov/pubmed/10050915) .
47. <sup>^</sup> Woods, William G. (1994). "An Introduction to Boron: History, Sources, Uses, and Chemistry". *Environmental Health Perspectives* **102**, Supplement 7: 5–11. PMC 1566642 (http://www.pubmedcentral.gov/articlerender.fcgi?tool=pmcentrez&artid=1566642) . PMID 7889881 (http://www.ncbi.nlm.nih.gov/pubmed/7889881) .
48. <sup>^ a b</sup> Kostick, Dennis S. (2006). "Mineral Yearbook: Boron" (http://minerals.usgs.gov/minerals/pubs/commodity/boron/myb1-2006-boron.pdf) (PDF). United States Geological Survey. http://minerals.usgs.gov/minerals/pubs/commodity/boron/myb1-2006-boron.pdf. Retrieved 2008-09-20.
49. <sup>^</sup> "Mineral Commodity Summaries: Boron" (http://minerals.usgs.gov/minerals/pubs/commodity/boron/mcs-2008-boron.pdf) (PDF). United States Geological Survey. 2008. http://minerals.usgs.gov/minerals/pubs/commodity/boron/mcs-2008-boron.pdf. Retrieved 2008-09-20.
50. <sup>^</sup> "Developments in the Economic Sector (of Turkey)" (http://www.byegm.gov.tr/YAYINLARIMIZ/kitaplar/turkiye2006/english/302-303.htm) . Turkish government. http://www.byegm.gov.tr/YAYINLARIMIZ/kitaplar/turkiye2006/english/302-303.htm. Retrieved 2007-12-21.
51. <sup>^</sup> Simmons, R.; Ahsian, N.; Raven, H. (2007). *The Book of Stones: Who They Are and What They Teach*. North Atlantic Books. pp. 421–422. ISBN 1556436688.
52. <sup>^</sup> Kistler, R. B. (1994). "Boron and Borates" (http://kisi.deu.edu.tr/cahit.helvacı/Boron.pdf) . *Industrial Minerals and Rocks* (Society of Mining, Metallurgy and Exploration, Inc.): 171–186. http://kisi.deu.edu.tr/cahit.helvacı/Boron.pdf.
53. <sup>^</sup> Zbayolu, G.; Poslu, K. (1992). "Mining and Processing of Borates in Turkey". *Mineral Processing and Extractive Metallurgy Review* **9** (1–4): 245–254. doi:10.1080/08827509208952709 (http://dx.doi.org/10.1080%2F08827509208952709) .
54. <sup>^</sup> Kar, Y.; Şen, Nejdet; Demİrbaş, Ayhan (2006). "Boron Minerals in Turkey, Their Application Areas and Importance for the Country's Economy". *Minerals & Energy – Raw Materials Report* **20** (3–4): 2–10. doi:10.1080/14041040500504293 (http://dx.doi.org/10.1080%2F14041040500504293) .
55. <sup>^</sup> Berger, L. I. (1996). *Semiconductor materials*. CRC Press. pp. 37–43. ISBN 0849389127.
56. <sup>^</sup> "Boron Properties" (http://www.rareearth.org/boron\_properties.htm) . Los Alamos National Laboratory. http://www.rareearth.org/boron\_properties.htm. Retrieved 2008-09-18.
57. <sup>^ a b</sup> *The Economics of Boron, 11th edition*. Roskill Information Services, Ltd.. 2006. ISBN 0862145163.
58. <sup>^</sup> "Raw and Manufactured Materials 2006 Overview" (http://www.ceramicindustry.com/Articles/Cover\_Story/4b0b7a6ed1cb8010VgnVCM100000f932a8c0\_\_\_\_) . http://www.ceramicindustry.com/Articles/Cover\_Story/4b0b7a6ed1cb8010VgnVCM100000f932a8c0\_\_\_\_. Retrieved 2009-05-05.
59. <sup>^</sup> "Roskill reports: boron" (http://www.roskill.com/reports/boron) . Roskill. http://www.roskill.com/reports/boron. Retrieved 2009-05-05.
60. <sup>^</sup> "Boron: Statistics and Information" (http://minerals.usgs.gov/minerals/pubs/commodity/boron/) . USGS. http://minerals.usgs.gov/minerals/pubs/commodity/boron/. Retrieved 2009-05-05.
61. <sup>^ a b c</sup> Hammond, C. R. (2004). *The Elements, in Handbook of Chemistry and Physics 81st edition*. CRC press. ISBN 0849304857.
62. <sup>^</sup> Pfander, H. G. (1996). *Schott guide to glass* (2 ed.). Springer. p. 122. ISBN 041262060X.
63. <sup>^</sup> Herring, H. W. (1966). "Selected Mechanical and Physical Properties of Boron Filaments" (http://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/19660005941\_1966005941.pdf) . NASA. http://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/19660005941\_1966005941.pdf. Retrieved 2008-09-20.
64. <sup>^</sup> Layden, G. K. (1973). "Fracture behaviour of boron filaments". *Journal of Materials Science* **8** (11): 1581–1589. Bibcode 1973JMatS...8.1581L (http://adsabs.harvard.edu/abs/1973JMatS...8.1581L) . doi:10.1007/BF00754893 (http://dx.doi.org/10.1007%2FBF00754893) .
65. <sup>^</sup> Cooke, Theodore F. (1991). "Inorganic Fibers—A Literature Review". *Journal of the American Ceramic Society* **74** (12): 2959–2978. doi:10.1111/j.1151-2916.1991.tb04289.x (http://dx.doi.org/10.1111%2Fj.1151-2916.1991.tb04289.x) .
66. <sup>^</sup> Johansson, S.; Schweitz, Jan-Åke; Westberg, Helena; Boman, Mats (1992). "Microfabrication of three-dimensional boron structures by laser chemical processing". *Journal Applied Physics* **72** (12): 5956–5963. doi:10.1063/1.351904 (http://dx.doi.org/10.1063%2F1.351904) .
67. <sup>^</sup> Record (http://householdproducts.nlm.nih.gov/cgi-bin/household/brands?tbl=chem&id=136) in the Household Products Database of NLM
68. <sup>^ a b</sup> Klotz, J. H.; Moss, JI; Zhao, R; Davis Jr, LR; Patterson, RS (1994). "Oral toxicity of boric acid and other boron compounds to immature cat fleas (Siphonaptera: Pulicidae)" (http://grande.nal.usda.gov/ibids/index.php?mode2=detail&origin=ibids\_references&therow=51171) . *J. Econ. Entomol.* **87** (6): 1534–1536. PMID 7836612 (http://www.ncbi.nlm.nih.gov/pubmed/7836612) . http://grande.nal.usda.gov/ibids/index.php?mode2=detail&origin=ibids\_references&therow=51171.
69. <sup>^</sup> May, Gary S.; Spanos, Costas J. (2006). *Fundamentals of semiconductor manufacturing and process control*. John Wiley and Sons. pp. 51–54. ISBN 0471784060.
70. <sup>^</sup> Sherer, J. Michael (2005). *Semiconductor industry: wafer fab exhaust management*. CRC Press. pp. 39–60. ISBN 1574447203.
71. <sup>^</sup> Ehrenfried Zschech, Caroline Whelan, Thomas Mikolajick (2005). *Materials for information technology: devices, interconnects and packaging*. Birkhäuser. p. 44. ISBN 1852339411.

72. ^ Gogotsi, Y. G. and Andrievski, R.A. (1999). *Materials Science of Carbides, Nitrides and Borides*. Springer. pp. 270–270. ISBN 0792357078.
73. ^ Weimer, Alan W. (1997). *Carbide, Nitride and Boride Materials Synthesis and Processing*. Chapman & Hall (London, New York). ISBN 0-412-54060-6.
74. ^ Solozhenko, V. L.; Kurakevych, Oleksandr O.; Le Godec, Yann; Mezouar, Mohamed; Mezouar, Mohamed (2009). "Ultimate Metastable Solubility of Boron in Diamond: Synthesis of Superhard Diamondlike BC5". *Phys. Rev. Lett.* **102** (1): 015506. Bibcode 2009PhRvL.102a5506S (http://adsabs.harvard.edu/abs/2009PhRvL.102a5506S) . doi:10.1103/PhysRevLett.102.015506 (http://dx.doi.org/10.1103/PhysRevLett.102.015506) . PMID 19257210 (http://www.ncbi.nlm.nih.gov/pubmed/19257210) .
75. ^ <sup>a</sup> <sup>b</sup> Qin, Jiaqian; He, Duanwei; Wang, Jianghua; Fang, Leiming; Lei, Li; Li, Yongjun; Hu, Juan; Kou, Zili et al. (2008). "Is Rhenium Diboride a Superhard Material?". *Advanced Materials* **20** (24): 4780. doi:10.1002/adma.200801471 (http://dx.doi.org/10.1002/2Fadma.200801471) .
76. ^ Wentorf, R. H. (1957). "Cubic form of boron nitride". *J. Chem Phys.* **26** (4): 956. doi:10.1063/1.1745964 (http://dx.doi.org/10.1063/2F1.1745964) .
77. ^ Schmidt, Jürgen; Boehling, Marian; Burkhardt, Ulrich; Grin, Yuri (2007). "Preparation of titanium diboride TiB<sub>2</sub> by spark plasma sintering at slow heating rate". *Science and Technology of Advanced Materials* **8** (5): 376. doi:10.1016/j.stam.2007.06.009 (http://dx.doi.org/10.1016/2Fj.stam.2007.06.009) .
78. ^ Kosanke, B. J. et al. (2004). *Pyrotechnic Chemistry*. Journal of Pyrotechnics., pp. 419. ISBN 9781889526157.
79. ^ "Borax Decahydrate" (http://chemicaland21.com/industrialchem/inorganic/BORAX%20DECAHYDRATE.htm) . http://chemicaland21.com/industrialchem/inorganic/BORAX%20DECAHYDRATE.htm. Retrieved 2009-05-05.
80. ^ Davies, A. C. (1992). *The Science and Practice of Welding: Welding science and technology*. Cambridge University Press. p. 56. ISBN 052143565X.
81. ^ Horrocks, A.R. and Price, D. (2001). *Fire Retardant Materials*. Woodhead Publishing Ltd.. p. 55. ISBN 1855734192.
82. ^ Ide, F. (2003). "Information technology and polymers. Flat panel display" (http://sciencelinks.jp/j-east/article/200311/000020031103A0287941.php) . *Engineering Materials* **51**: 84. http://sciencelinks.jp/j-east/article/200311/000020031103A0287941.php.
83. ^ "Lockheed SR-71 Blackbird" (http://www.marchfield.org/sr71a.htm) . March Field Air Museum. http://www.marchfield.org/sr71a.htm. Retrieved 2009-05-05.
84. ^ A. Young (2008). *The Saturn V F-1 Engine: Powering Apollo Into History*. Springer. p. 86. ISBN 0387096299.
85. ^ Canfield,, Paul C.; Crabtree, George W. (2003). "Magnesium Diboride: Better Late than Never" (http://www.cmp.ameslab.gov/personnel/canfield/pub/pt0303.pdf) . *Physics Today* **56** (3): 34–41. doi:10.1063/1.1570770 (http://dx.doi.org/10.1063/2F1.1570770) . http://www.cmp.ameslab.gov/personnel/canfield/pub/pt0303.pdf.
86. ^ Braccini, Valeria; Nardelli, D; Penco, R; Grasso, G (2007). "Development of ex situ processed MgB<sub>2</sub> wires and their applications to magnets". *Physica C: Superconductivity* **456** (1–2): 209–217. Bibcode 2007PhyC..456..209B (http://adsabs.harvard.edu/abs/2007PhyC..456..209B) . doi:10.1016/j.physc.2007.01.030 (http://dx.doi.org/10.1016/2Fj.physc.2007.01.030) .
87. ^ Wu, Xiaowei; Chandel, R. S.; Li, Hang (2001). "Evaluation of transient liquid phase bonding between nickel-based superalloys". *Journal of Materials Science* **36** (6): 1539–1546. doi:10.1023/A:1017513200502 (http://dx.doi.org/10.1023/2FA%3A1017513200502) .
88. ^ Hütter, R. et al.; Keller-Schierlein, W; Knüsel, F; Prelog, V; Rodgers Jr, GC; Suter, P; Vogel, G; Voser, W et al. (1967). "Stoffwechselprodukte von Mikroorganismen. 57. Mitteilung. Boromycin". *Helvetica Chimica Acta* **50** (6): 1533–1539. doi:10.1002/hlca.19670500612 (http://dx.doi.org/10.1002/2Fhlca.19670500612) . PMID 6081908 (http://www.ncbi.nlm.nih.gov/pubmed/6081908) .
89. ^ Dumitz, J. D. et al.; Hawley, DM; Miklos, D; White, DN; Berlin, Y; Marusić, R; Prelog, V (1971). "Structure of boromycin". *Helvetica Chimica Acta* **54** (6): 1709–1713. doi:10.1002/hlca.19710540624 (http://dx.doi.org/10.1002/2Fhlca.19710540624) . PMID 5131791 (http://www.ncbi.nlm.nih.gov/pubmed/5131791) .
90. ^ Mahler, R. L.. "Essential Plant Micronutrients. Boron in Idaho" (http://info.ag.uidaho.edu/Resources/PDFs/CIS1085.pdf) . University of Idaho. http://info.ag.uidaho.edu/Resources/PDFs/CIS1085.pdf. Retrieved 2009-05-05.
91. ^ "Functions of Boron in Plant Nutrition" (http://www.borax.com/agriculture/files/an203.pdf) (PDF). U.S. Borax Inc.. http://www.borax.com/agriculture/files/an203.pdf.
92. ^ Blevins, Dale G.; Lukaszewski, KM (1998). "Functions of Boron in Plant Nutrition". *Annual Review of Plant Physiology and Plant Molecular Biology* **49**: 481–500. doi:10.1146/annurev.arplant.49.1.481 (http://dx.doi.org/10.1146/2Fannurev.arplant.49.1.481) . PMID 15012243 (http://www.ncbi.nlm.nih.gov/pubmed/15012243) .
93. ^ Nielsen, Forrest H. (1998). "Ultratrace elements in nutrition: Current knowledge and speculation". *The Journal of Trace Elements in Experimental Medicine* **11** (2–3): 251–274. doi:10.1002/(SICI)1520-670X(1998)11:2/3<251::AID-JTRA15>3.0.CO;2-Q (http://dx.doi.org/10.1002/2F%28SICI%291520-670X%281998%2911%3A2%2F3%3C251%3A%3AAID-JTRA15%3E3.0.CO%3B2-Q) .
94. ^ "Boron" (http://web.archive.org/web/20080524054321/http://www.pdrhealth.com/drug\_info/nmdrugprofiles/nutsupdrugs/bor\_0040.shtml) . PDRhealth. Archived from the original (http://www.pdrhealth.com/drug\_info/nmdrugprofiles/nutsupdrugs/bor\_0040.shtml) on 24 May 2008. http://web.archive.org/web/20080524054321/http://www.pdrhealth.com/drug\_info/nmdrugprofiles/nutsupdrugs/bor\_0040.shtml. Retrieved 2008-09-18.
95. ^ Zook, E. G. (1965). "Total boron". *J. Assoc. Off Agric. Chem* **48**: 850.
96. ^ United States. Environmental Protection Agency. Office of Water, U. S. Environmental Protection Agency Staff (1993). *Health advisories for drinking water contaminants: United States Environmental Protection Agency Office of Water health advisories* (http://books.google.com/?id=trUdm-GXchIC&pg=PA84) . CRC Press. p. 84. ISBN 087371931X. http://books.google.com/?id=trUdm-GXchIC&pg=PA84.
97. ^ Silverman, L.; Trego, Katherine (1953). "Corrections-Colorimetric Microdetermination of Boron By The Curcumin-Acetone Solution Method". *Anal. Chem.* **25** (11): 1639. doi:10.1021/ac60083a061 (http://dx.doi.org/10.1021/2Ffac60083a061) .
98. ^ "Boric acid" (http://chemicaland21.com/industrialchem/inorganic/BORIC%20ACID.htm) . http://chemicaland21.com/industrialchem/inorganic/BORIC%20ACID.htm. Retrieved 2009-05-05.

99. ^ <http://www.pharmainfo.net/reviews/boron-neutron-capture-therapy-overview> Overview of neutron capture therapy pharmaceuticals.
100. ^ Travers, Richard L.; Rennie, George; Newnham, Rex (1990). "Boron and Arthritis: The Results of a Double-blind Pilot Study". *Journal of Nutritional & Environmental Medicine* **1** (2): 127–132. doi:10.3109/13590849009003147 (<http://dx.doi.org/10.3109%2F13590849009003147>) .
101. ^ Bonvini P, Zorzi E, Basso G, Rosolen A (2007). "Bortezomib-mediated 26S proteasome inhibition causes cell-cycle arrest and induces apoptosis in CD-30+ anaplastic large cell lymphoma". *Leukemia* **21** (4): 838–42. doi:10.1038/sj.leu.2404528 (<http://dx.doi.org/10.1038%2Fsj.leu.2404528>) . PMID 17268529 (<http://www.ncbi.nlm.nih.gov/pubmed/17268529>) .
102. ^ Garrett, Donald E. (1998). *Borates* (<http://books.google.com/?id=imMJJP5T5rsC&pg=PA385>) . Academic Press. p. 385. ISBN 0122760603. <http://books.google.com/?id=imMJJP5T5rsC&pg=PA385>.
103. ^ "Environmental Health Criteria 204: Boron" (<http://www.inchem.org/documents/ehc/ehc/ehc204.htm>) . the IPCS. 1998. <http://www.inchem.org/documents/ehc/ehc/ehc204.htm>. Retrieved 2009-05-05.
104. ^ Vithana, En; Morgan, P; Sundaresan, P; Ebenezer, Nd; Tan, Dt; Mohamed, Md; Anand, S; Khine, Ko; Venkataraman, D; Yong, Vh; Salto -Tellez, M; Venkatraman, A; Guo, K; Hemadevi, B; Srinivasan, M; Prajna, V; Khine, M; Casey, Jr; Inglehearn, Cf; Aung, T (July 2006). "Mutations in sodium-borate cotransporter SLC4A11 cause recessive congenital hereditary endothelial dystrophy (CHED2)". *Nature genetics* **38** (7): 755–7. doi:10.1038/ng1824 (<http://dx.doi.org/10.1038%2Fng1824>) . ISSN 1061-4036 (<http://www.worldcat.org/issn/1061-4036>) . PMID 16767101 (<http://www.ncbi.nlm.nih.gov/pubmed/16767101>) .

## External links

- The Periodic Table of Videos video of Boron (<http://www.youtube.com/?v=JzqdHkpXuy4>) at YouTube
- Boron (<http://www.du.edu/~jcalvert/phys/boron.htm>)
- WebElements.com – Boron (<http://www.webelements.com/boron/>)
- National Pollutant Inventory – Boron and compounds (<http://www.npi.gov.au/database/substance-info/profiles/15.html>)

Retrieved from "<http://en.wikipedia.org/wiki/Boron>"

Categories: Chemical elements | Dietary minerals | Metalloids | Boron | Pyrotechnic fuels | Rocket fuels | Neutron poisons | Nuclear fusion fuels | Biology and pharmacology of chemical elements | Reducing agents

---

- This page was last modified on 30 June 2011 at 18:13.
  - Text is available under the Creative Commons Attribution-ShareAlike License; additional terms may apply. See Terms of use for details.
- Wikipedia® is a registered trademark of the Wikimedia Foundation, Inc., a non-profit organization.