The boron family contains the semi-metal boron (B) and metals aluminum (Al), gallium (Ga), indium (In), and thallium (Tl).

Properties and Periodic Trends

These elements are found in Group 13 (XIII) of the p block in the Periodic Table of Elements. Aluminum, gallium, indium, and thallium are metallic. They each have three electrons in their outermost shell (a full s orbital and one electron in the p orbital) with the valence electron configuration ns\(^2\)np\(^1\). The boron family adopts oxidation states +3 or +1. The +3 oxidation states are favorable except for the heavier elements, such as Tl, which prefer the +1 oxidation state due to its stability; this is known as the inert pair effect. The elements generally follow periodic trends except for certain Tl deviations:

- Atomic radius increases down the group (Tl has the largest atomic radius.)
- Electrode potential increases down the group (reactivity decreases down the group)
- Ionization Energy decreases going down the group (because the electrons are farther from the core and therefore are easier to remove; Tl does not fit this trend)*

Table 1: Properties & Trends of Group 3 Elements

<table>
<thead>
<tr>
<th>Elemental Symbol</th>
<th>Atomic Number (Z)</th>
<th>Molecular Mass (g/mol)</th>
<th>Melting Point °C</th>
<th>Standard Reduction Potential (V)</th>
<th>Ionization Energy (kJ/mol)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Boron</td>
<td>B</td>
<td>5</td>
<td>10.811</td>
<td>2076</td>
<td>-</td>
</tr>
<tr>
<td>Aluminum</td>
<td>Al</td>
<td>13</td>
<td>26,9815</td>
<td>660</td>
<td>-1.68</td>
</tr>
<tr>
<td>Gallium</td>
<td>Ga</td>
<td>31</td>
<td>69.723</td>
<td>29.8</td>
<td>-0.56</td>
</tr>
<tr>
<td>Indium</td>
<td>In</td>
<td>49</td>
<td>114.818</td>
<td>156</td>
<td>0.34</td>
</tr>
<tr>
<td>Thallium</td>
<td>Th</td>
<td>81</td>
<td>205.383</td>
<td>303</td>
<td>+0.72</td>
</tr>
</tbody>
</table>

Boron

Boron is the first element of Group 13 and is the only metalloid of the group. Its chemical symbol is B, and it has an atomic number of 5. Boron has the electron configuration [He] 2s\(^2\)2p\(^1\) and prefers an oxidation state of +3. Boron has no natural elemental form; it forms compounds which are abundant in the Earth's crust. Boron is an essential nutrient for plants. There are a few locations where boron ores, known as borax, are found in great concentrations. Due to its lack of a complete octet, boron is a Lewis acid. It tends to form hydrides, the simplest of which is diborane, \(B_2H_6\). Boron hydrides are used to synthesize organic compounds. One of the main compounds used to form other boron compounds is boric acid, which is a weak acid and is formed in the following two-step reaction:

\[
[B_2O_{3\; (s)} + 3 \; H_2O \;((l)) \rightarrow 2 \; B(OH)_{(aq)}] \\
[B(OH)_{(aq)} + 2 \; H_2O \;((l)) \rightarrow H_3O^+_{(aq)} + B(OH)^-_{(aq)}]
\]
Boron can be crystallized from a solution of hydrogen peroxide and borax to produce sodium perborate, a bleach alternative. The bleaching ability of perborate is due to the two peroxy groups bound to the boron atoms.

## Aluminum

Aluminum is the most important metal in the boron family, with the chemical symbol Al and atomic number 13. It is used in lightweight alloys and is an active metal. It has the electron configuration [Ne] 2s²2p¹, and usually adopts a +3 oxidation state. This element is the most abundant metal in the Earth’s crust (7.5-8.4%). Even though it is very abundant, before 1886 aluminum was considered a semiprecious metal; it was difficult to isolate due to its high melting point. Aluminum is very expensive to produce, because the electrolysis of one mole of aluminum requires three moles of electrons:

\[
\text{\text{[Al}^{3+} + 3\text{e}^- \rightarrow \text{Al(l)}]}\]

Aluminum is a soft, malleable metal that is silver or gray in color. It is highly reactive, and therefore found in nature in compounds. Aluminum does not appear to react with water because it is aluminum is protected by a layer of Al₂O₃; this effect is known as anodizing. The thickness of the Al₂O₃ layer varies based on galvanic reactions, but it prevents the metal from oxidizing further. Aluminum is used in many alloys to prevent corrosion.

- **Aluminum Oxide (Al₂O₃):** Commonly referred to as alumina, it has highly desirable metallic characteristics due to its strong ionic bonding. It is an excellent thermal insulator, and forms corundum upon crystallization. Corundum exist in several forms, including in sapphires and rubies. The differences in the colors of these gems are due to transition metal impurities in their corundum structure.
- **Aluminum Sulfate Al₂(SO₄)₃:** Very important commercial compound. Used in sizing paper (paper in which waxes and glues are used to make the paper more water resistant.) Aluminum sulfate, however, has an acidic properties that may deteriorate the paper.

Aluminum can dissolve in both acids and bases—it is amphoteric. In an aqueous OH⁻ solution it produce Al(OH)₄⁻, and in an aqueous H₃O⁺ solution it produce [Al(H₂O)₆]³⁺

Another important feature of aluminum is that it is a good reducing agent due to its +3 oxidation state. It can therefore react with acids to reduce H⁺(aq) to H₂(g). For example:

\[
\text{[2Al (s) + 6H}^+\text{(aq) \rightarrow 2Al}^{3+}\text{(aq) + 3H}_2\text{(g)}]}\]

Aluminum can also extract oxygen from any metal oxide. The following reaction, which is known as the thermite reaction, is very exothermic:

\[
\text{[Fe}_2\text{O}_3\text{(s) + 2 Al(s) \rightarrow Al}_2\text{O}_3\text{(s) + 2 Fe(l)}]}\]

## Gallium

Gallium has the chemical symbol Ga and the atomic number 31. It has the electron configuration [Ar] 2s²2p¹ and a +3 oxidation state. The melting point is 29.8°C, slightly above room temperature. Gallium has the second lowest melting point (after mercury) and can remain in the liquid phase at a larger range of temperatures than any other substance. Gallium is industrially important because it forms gallium arsenide (GaAs), which converts light directly into electricity.
Gallium is also used in conjunction with aluminum to generate hydrogen. In a process similar to the thermite reaction, aluminum extracts oxygen from water and releases hydrogen gas. However, as mentioned above, aluminum forms a protective coat in the presence of water. Combining gallium and aluminum prevents the formation of this protective layer, allowing aluminum to reduce water to hydrogen.[7]

**Indium**

Indium has the chemical symbol In and the atomic number 49. It has the electron configuration [Kr] 2s²2p¹ and may adopt the +1 or +3 oxidation state; however, the +3 state is more common. It is a soft, malleable metal that is similar to gallium. Indium forms InAs, which is found in photoconductors in optical instruments. The physical properties of indium include its silver-white color and the "tin cry" it makes when bent. Indium is soluble in acids, but does not react with oxygen at room temperature. It is obtained by separation from zinc ores. Indium is mainly used to make alloys, and only a small amount is required to enhance the metal strength. For example, indium is added to gold or platinum to make the metals more useful industrial tools.

**Thallium**

Thallium has the chemical symbol Tl and atomic number 81. It has the electron configuration [Xe] 2s²2p¹ and has a +3 or +1 oxidation state. As stated above, because thallium is heavy, it has a greater stability in the +1 oxidation state (inert pair effect). Therefore, it is found more commonly in its +1 oxidation state. Thallium is soft and malleable. It is poisonous, but used in high-temperature superconductors. Because of its toxicity, thallium was widely used in insecticide and rat poison until this usage was prohibited in 1975 in the U.S.

**Diagonal Relationship of Beryllium and Aluminum**

Both Be²⁺ and Al³⁺ are hydrated to produce [Be(H₂O)₄]²⁺ and Al(H₂O)₆³⁺, respectively. When reacted with water, both compounds produce hydronium ions, making them slightly acidic. Another similarity between aluminum and beryllium is that they are amphoteric, and their hydroxides are very basic. Both metals also react with oxygen to produce oxide coatings capable of protecting other metals from corrosion. Both metals also react with halides that can act as Lewis acids.

**References**

Problems

( highlight the blue areas to find the answers)

1. T/F In reality, aluminum forms a protective layer and does not react with water.

2. Which statement about Gallium is false?
   a. It melts on contact with human hands
   b. It can combine with aluminum to reduce water
   c. It is mainly found in the oxidation state +1
   d. It can form a good source of hydrogen

3. T/F Thallium is highly toxic and therefore it is commonly used for rat poisons and insecticides in the United States.

4. Boron:
   a. has the electron configuration [Ne] 2s^2 2p^1
   b. is the first metal of Group 13.
   c. has an atomic number 6.
   d. is an important element that we use in our daily lives.
   e. All of the above is correct.

5. Aluminum Oxide:
   a. has poor corrosion resistance
   b. is not a very good thermal insulator
   c. in its crystalline form it is called corundum
   d. is not a very reactive metal

6. T/F Aluminum is amphoteric

7. Which element is the only metalloid in the boron family?

8. When beryllium reacts with a halide, which of the following is true?
   a. It acts as a Lewis base
   b. It forms a covalent bond
c. It forms a Lewis acid

9. What is the electron configuration of thallium?

\[ \text{[Xe]} 2s^2 2p^1 \]

10. Which statement is False?

a. Thallium is the heaviest element.

b. Boron has the highest melting point.

c. Electron potential increases going down the group.

d. Thallium has the lowest ionization energy.

e. All of the above are correct.

Contributors

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