The nitrogen family includes the following compounds: nitrogen (N), phosphorus (P), arsenic (As), antimony (Sb), and bismuth (Bi). All Group 15 elements have the electron configuration ns\(^2\)np\(^3\) in their outer shell, where \(n\) is equal to the principal quantum number. The nitrogen family is located in the p-block in Group 15, as shown below.

### Periodic Trends

All Group 15 elements tend to follow the general periodic trends:

- Electronegativity (the atom’s ability of attracting electrons) decreases down the group.
- Ionization energy (the amount of energy required to remove an electron from the atom in its gas phase) decreases down the group.
- Atomic radii increase in size down the group.
- Electron affinity (the ability of the atom to accept an electron) decreases down the group.
- Melting point (amount of energy required to break bonds to change a solid phase substance to a liquid phase substance) increases down the group.
- Boiling point (amount of energy required to break bonds to change a liquid phase substance to a gas) increases down the group.
- Metallic character increases down the group.

### Properties of Group 15 Elements

<table>
<thead>
<tr>
<th>Element/Symbol</th>
<th>Atomic Number</th>
<th>Mass</th>
<th>Electron Configuration</th>
<th>Covalent Radius</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nitrogen (N)</td>
<td>7</td>
<td>14.01</td>
<td>1s(^2) 2s(^2) 2p(^3)</td>
<td>75</td>
</tr>
<tr>
<td>Phosphorus (P)</td>
<td>15</td>
<td>30.97</td>
<td>[Ne]3s(^2) 3p(^3)</td>
<td>110</td>
</tr>
<tr>
<td>Arsenic (As)</td>
<td>33</td>
<td>74.92</td>
<td>[Ar] 3d(^{10}) 4s(^2) 4p(^3)</td>
<td>121</td>
</tr>
<tr>
<td>Antimony (Sb)</td>
<td>51</td>
<td>121.76</td>
<td>[Kr] 4d(^{10}) 5s(^2) 5p(^3)</td>
<td>140</td>
</tr>
<tr>
<td>Bismuth (Bi)</td>
<td>83</td>
<td>208.98</td>
<td>[Xe] 4f(^{14}) 5d(^{10}) 6s(^2) 6p(^3)</td>
<td>155</td>
</tr>
</tbody>
</table>
Nitrogen

Nitrogen was discovered in 1770 by Scheele and Priestley. This nonmetallic element has no color, taste or odor and is present in nature as a noncombustible gas. When compared with the rest of Group 15, nitrogen has the highest electronegativity which makes it the most nonmetallic of the group. The common oxidation states of nitrogen are +5, +3, and -3. Nitrogen makes up about 0.002% of the earth’s crust; however, it constitutes 78% of the earth’s atmosphere by volume. Nitrogen has also been discovered in the atmospheres of Venus and Mars. Venus has a 3.5% nitrogen volume in its atmosphere and Mars has a 2.7% nitrogen volume in its atmosphere. Nitrogen is found naturally in animal and plant proteins and in fossilized remains of ancient plant life. Important nitrogen-containing minerals are niter, KNO$_3$, and soda niter, NaNO$_3$, which are found in desert regions and are important components of fertilizers. Before the process of converting nitrogen into ammonia was discovered, sources of nitrogen were limited. One of the processes of converting nitrogen to ammonia, the Haber-Bosch process, is very important for the production of nitrogen. Nitrogen has very little solubility in liquids. N$_2$ does not have any allotropes.

The unusually stable N$_2$(g) nitrogen gas is the source in which all nitrogen compounds are ultimately derived. N$_2$(g) is stable due to its electronic structure: the bond between the two nitrogen atoms of N$_2$ is a triple covalent bond which is strong and hard to break. The enthalpy change associated with breaking the bonds in N$_2$ is highly endothermic: $\Delta H = +945.4$ kJ. Nitrogen gas is used as a refrigerant, metal treatment, and pressurized gas for oil recovery. Additionally, the Gibbs energies of formation of nitrogen compounds show that their formations are nonspontaneous, and the following process does not occur at normal temperatures:

$$\frac{1}{2} \text{N}_2(g) + \frac{1}{2} \text{O}_2 \rightarrow \text{NO}(g)$$

with

$$\Delta G_f = +86.55 \text{kJ/mol}$$

The oxides and oxyacids of nitrogen include nitrous oxide (N$_2$O), nitrogen oxide (NO), and nitrogen dioxide (NO$_2$). Nitrous oxide, also called “laughing gas,” is used in dental work, child birth, and to increase the speed of cars. Nitrogen oxide is found in smog and neurotransmitters. Hydrazine, N$_2$H$_4$, is a poisonous, colorless liquid that explodes in air. Hydrazine is a good reducing agent, and methyl hydrazine is commonly used as a rocket fuel.

Phosphorus

Phosphorus is a nonmetallic element. The most common oxidation state of phosphorus is -3. Phosphorus is the eleventh most abundant element, making up 0.11% of the earth’s crust. The main source of phosphorus compounds is phosphorus rocks. Phosphorous is not found pure in nature, but in the form of apatite ores. These include compounds such as fluorapatite (Ca$_5$(PO$_4$)$_3$F), which in fluoridated water is used to strengthen teeth, and hydroxylapatite (Ca$_{10}$(OH)$_2$(PO$_4$)$_6$), a major component of tooth enamel and bone material. Phosphorus exhibits allotropic forms: the most common forms at room temperature are white phosphorus and red phosphorus. White phosphorus is a white, waxy solid that can be cut with a knife. It forms a tetrahedral molecule, P$_4$. White phosphorus is toxic, while red phosphorus is nontoxic. Red phosphorous forms when white phosphorous is heated to 573 Kelvin and not exposed to air. Red phosphorus is less reactive than white phosphorus. Red phosphorus has a chain like polymeric structure, and is more stable. Both white and
red phosphorus are incendiary and have been used to make match tips, although the use of white phosphorus has been largely discontinued due to toxicity. Phosphorus has many applications: phosphorus trichloride (PCl$_3$) is used in soaps, detergents, plastics, synthetic rubber nylon, motor oils, insecticides and herbicides; phosphoric acid, H$_3$PO$_4$, is used in fertilizers; phosphorus is also prevalent in the food industry, used in baking powders, instant cereals, cheese, the curing of ham, and in the tartness of soft drinks.

**Arsenic**

Arsenic is a highly poisonous metalloid. Because it is a metalloid, arsenic has a high density, moderate thermal conductivity, and a limited ability to conduct electricity. The oxidation states of arsenic are +5, +3, +2, +1, and -3. The three allotropic forms of arsenic are yellow, black, and gray; the gray allotrope is the most common. Compounds of arsenic are used in insecticides, weed killers, and alloys. The oxide of arsenic is amphoteric, meaning it can act as both an acid and a base. Arsenic is mainly obtained by heating arsenic-containing sulfides. The chemical formula for this process is given below:

\[
\text{FeAsS}_{(s)} \rightarrow \text{FeS}_{(s)} + \text{As}_{(g)}
\]

The \(\text{As}_{(g)}\) deposits as \(\text{As}_{(s)}\) which can then be used to make other compounds. Arsenic can also be obtained by the reduction of arsenic(III) oxide with \(\text{CO}_{(g)}\).

**Antimony**

Antimony is also a metalloid. The oxidation states of antimony are +3, -3, and +5. Antimony exhibits allotropy; the most stable allotrope is the metallic form, which is similar in properties to arsenic: high density, moderate thermal conductivity, and a limited ability to conduct electricity. The oxide of antimony is antimony (III) oxide which is amphoteric, meaning it can act as both an acid and a base. Antimony is obtained mainly from its sulfide ores, and it vaporizes at low temperatures. Along with arsenic, antimony is commonly used in alloys. Arsenic, antimony, and lead form an alloy with desirable properties for electrodes in lead-acid batteries. Arsenic and antimony are also used to produce semiconductor materials such as GaAs, GaSb, and InSb in electronic devices.

**Bismuth**

Bismuth is a metallic element. The oxidation states of bismuth are +3 and +5. Bismuth is a poor metal (one with significant covalent character) that is similar to both arsenic and antimony. Bismuth is commonly used in cosmetic products and medicine. Out of the group, bismuth has the lowest electronegativity and ionization energy, which means that it is more likely to lose an electron than the rest of the Group 15 elements. This is why bismuth is the most metallic of Group 15. Bismuth is also a poor electrical conductor. The oxide of bismuth is bismuth(III) oxide; it acts as a base, as expected for a metal oxides. Bismuth is obtained as a by-product of the refining of other metals, allowing other metals to recycle their by-products into bismuth.
References


Problems

1. How much of the earth's crust is made up of nitrogen?
2. How much of earth's crust is not made up of phosphorus?
3. What kind of bond does N\(_2\) have?
4. How are red phosphorus and white phosphorus related to each other?
5. What is the electron configuration of arsenic?
6. Does bismuth have metallic properties or nonmetallic properties?
7. True or False: nitrogen and phosphorus are metals.
8. Which Group 15 element has a greatest atomic radius?
9. Which Group 15 element is the strongest reducing agent?
10. True or False: bismuth exhibits the most metallic character.
11. What is the most common physical form of nitrogen?
12. What is the process in which nitrogen can convert into ammonia?
13. Which element has the highest first ionization energy?
14. Complete and balance the following reaction: \( _{\text{N}_2(g)} + _\text{H}_2(g) \rightarrow \) ______
15. What is the common oxidation state of all Group 15 elements?

Answers

1. 0.002% of earth's crust is made of nitrogen.
2. Earth's crust is made up of 0.11% of phosphorus, so 99.89% of earth's crust is not made up of phosphorus.
3. N\(_2\) has a triple covalent bond that is strong and hard to break.
4. Red phosphorus and white phosphorus are both allotropes of phosphorus. Red phosphorus comes from white phosphorus when it is heated to about 573 Kelvin.
5. [Ar] 3d\(^{10}\) 4s\(^2\) 4p\(^3\)
6. Bismuth has metallic properties.
7. False; both nitrogen and phosphorus are nonmetals.
8. According to periodic trends, bismuth has the greatest atomic radius.
9. According to periodic trends, bismuth is the strongest reducing agent since it has an electronegativity value of 1.9 which is the same as Antimony but it has a lower ionization energy of 703 kJ/mol which means it is more likely to get oxidized.

10. True; bismuth is the only metallic element of Group 15.

11. The most common physical form of nitrogen is a colorless gas.

12. The process of converting nitrogen into ammonia is known as the Haber-Bosch process.

13. According to periodic trends, nitrogen would have the highest first ionization energy which means that it does not want to lose an electron the most.

14. \[ \text{N}_2(\text{g}) + 3\text{H}_2(\text{g}) \rightarrow 2\text{NH}_3(\text{g}) \]

15. The common oxidation state for all Group 15 elements is -3.

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