The oxygen family, also called the chalcogens, consists of the elements found in Group 16 of the periodic table and is considered among the main group elements. It consists of the elements oxygen, sulfur, selenium, tellurium, and polonium. These can be found in nature in both free and combined states. The group 16 elements are intimately related to life. We need oxygen all the time throughout our lives. Did you know that sulfur is also one of the essential elements of life? It is responsible for some of the protein structures in all living organisms. Many industries utilize sulfur, but emission of sulfur compounds is often seen more as a problem than the natural phenomenon. The metallic properties increase as the atomic number increases. The element polonium has no stable isotopes, and the isotope with mass number 209 has the longest half life of 103 years.

Properties and Periodic Trends

Properties of oxygen are very different from other elements of the group, but they all have 2 elections in the outer s orbital, and 4 electrons in the p orbitals, usually written as \(s^2p^4\)

The electron configurations for each element are given below:

- **Oxygen**: \(1s^2\, 2s^2\, 2p^4\)
- **Sulfur**: \(1s^2\, 2s^2p^6\, 3s^2p^4\)
- **Selenium**: \(1s^2\, 2s^2p^6\, 3s^2p^6d^{10}\, 4s^2p^4\)
- **Tellurium**: \(1s^2\, 2s^2p^6\, 3s^2p^6d^{10}\, 4s^2p^6d^{10}\, 5s^2p^4\)
- **Polonium**: \(1s^2\, 2s^2p^6\, 3s^2p^6d^{10}\, 4s^2p^6d^{10}f^{14}\, 5s^2p^6d^{10}\, 6s^2p^4\)

Example \(\PageIndex{1}\): Polonium

Polonium can be written as \([\text{Xe}]\, 6s^2\, 4f^{14}\, 5d^{10}\, 6p^4\)

The trends of their properties in this group are interesting. Knowing the trend allows us to predict their reactions with other elements. Most trends are true for all groups of elements, and the group trends are due mostly to the size of the atoms and number of electrons per atom. The trends are described below:

1. The metallic properties increase in the order oxygen, sulfur, selenium, tellurium, or polonium. Polonium is essentially a metal. It was discovered by M. Curie, who named it after her native country Poland.
2. Electronegativity, ionization energy (or ionization potential IP), and electron affinity decrease for the group as atomic weight increases.
3. The atomic radii and melting point increase.
4. Oxygen differs from sulfur in chemical properties due to its small size. The differences between \(\text{O}\) and \(\text{S}\) are more than the differences between other members.

Metallic character increases down the group, with tellurium classified as a metalloid and polonium as a metal. Melting point, boiling point, density, atomic radius, and ionic radius all increase down the group. Ionization energy decreases down the group. The most common oxidation state is -2; however, sulfur can also exist at a +4 and +6 state, and +2, +4, and +6 oxidation states are possible for Se, Te, and Po.
**Table 1: Select properties of Group 16 elements**

<table>
<thead>
<tr>
<th></th>
<th>Oxygen</th>
<th>Sulfur</th>
<th>Selenium</th>
<th>Tellurium</th>
<th>Polonium</th>
</tr>
</thead>
<tbody>
<tr>
<td>Boiling Pt (°C)</td>
<td>-182.962</td>
<td>444.674</td>
<td>685</td>
<td>989.9</td>
<td>962</td>
</tr>
<tr>
<td>Ionization Energy (kJ/mol)</td>
<td>1314</td>
<td>1000</td>
<td>941</td>
<td>869</td>
<td>812</td>
</tr>
<tr>
<td>Ionic Radius (pm)</td>
<td>140</td>
<td>184</td>
<td>198</td>
<td>221</td>
<td></td>
</tr>
</tbody>
</table>

**Oxygen**

Oxygen is a gas at room temperature and 1 atm, and is colorless, odorless, and tasteless. It is the most abundant element by mass in both the Earth's crust and the human body. It is second to nitrogen as the most abundant element in the atmosphere. There are many commercial uses for oxygen gas, which is typically obtained through fractional distillation. It is used in the manufacture of iron, steel, and other chemicals. It is also used in water treatment, as an oxidizer in rocket fuel, for medicinal purposes, and in petroleum refining.

Oxygen has two allotropes, O₂ and O₃. In general, O₂ (or dioxygen) is the form referred to when talking about the elemental or molecular form because it is the most common form of the element. The O₂ bond is very strong, and oxygen can also form strong bonds with other elements. However, compounds that contain oxygen are considered to be more thermodynamically stable than O₂.

The latter allotrope, ozone, is a pale-blue poisonous gas with a strong odor. It is a very good oxidizing agent, stronger than dioxygen, and can be used as a substitute for chlorine in purifying drinking water without giving the water an odd taste. However, because of its unstable nature it disappears and leaves the water unprotected from bacteria. Ozone at very high altitudes in the atmosphere is responsible for protecting the Earth's surface from ultraviolet radiation; however, at lower altitudes it becomes a major component of smog.

Oxygen's primary oxidation states are -2, -1, 0, and -1/2 (in O₂⁻), but -2 is the most common. Typically, compounds with oxygen in this oxidation state are called oxides. When oxygen reacts with metals, it forms oxides that are mostly ionic in nature. These can dissolve in water and react to form hydroxides; they are therefore called basic anhydrides or basic oxides. Nonmetal oxides, which form covalent bonds, are simple molecules with low melting and boiling points.

Compounds with oxygen in an oxidation state of -1 are referred to as peroxides. Examples of this type of compound include \( \text{Na}_2\text{O}_2 \) and \( \text{BaO}_2 \). When oxygen has an oxidation state of -1/2, as in \( \text{O}_2^- \), the compound is called a superoxide.

Oxygen is rarely the central atom in a structure and can never bond with more than 4 elements due to its small size and its inability to create an expanded valence shell. Oxygen reacts with hydrogen to form water, which is extensively hydrogen-bonded, has a large dipole moment, and is considered an universal solvent.

There are a wide variety of oxygen-containing compounds, both organic and inorganic: oxides, peroxides and
superoxides, alcohols, phenols, ethers, and carbonyl-containing compounds such as aldehydes, ketones, esters, amides, carbonates, carbamates, carboxylic acids and anhydrides.

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**Sulfur**

Sulfur is a solid at room temperature and 1 atm pressure. It is usually yellow, tasteless, and nearly odorless. It is the sixteenth most abundant element in Earth's crust. It exists naturally in a variety of forms, including elemental sulfur, sulfides, sulfates, and organosulfur compounds. Since the 1890s, sulfur has been mined using the Frasch process, which is useful for recovering sulfur from deposits that are under water or quicksand. Sulfur produced from this process is used in a variety of ways including in vulcanizing rubber and as fungicide to protect grapes and strawberries.

Sulfur is unique in its ability to form a wide range of allotropes, more than any other element in the periodic table. The most common state is the solid S₈ ring, as this is the most thermodynamically stable form at room temperature. Sulfur exists in the gaseous form in five different forms (S, S₂, S₄, S₆, and S₈). In order for sulfur to convert between these compounds, sufficient heat must be supplied.

Two common oxides of sulfur are sulfur dioxide (SO₂) and sulfur trioxide (SO₃). Sulfur dioxide is formed when sulfur is combusted in air, producing a toxic gas with a strong odor. These two compounds are used in the production of sulfuric acid, which is used in a variety of reactions. Sulfuric acid is one of the top manufactured chemicals in the United States, and is primarily used in the manufacture of fertilizers.

Sulfur also exhibits a wide range of oxidation states, with values ranging from -2 to +6. It is often the central ion in a compound and can easily bond with up to 6 atoms. In the presence of hydrogen it forms the compound hydrogen sulfide, H₂S, a poisonous gas incapable of forming hydrogen bonds and with a very small dipole moment. Hydrogen sulfide can easily be recognized by its strong odor that is similar to that of rotten eggs, but this smell can only be detected at low, nontoxic concentrations. This reaction with hydrogen epitomizes how differently oxygen and sulfur act despite their common valence electron configuration and common nonmetallic properties.

A variety of sulfur-containing compounds exist, many of them organic. The prefix *thio-* in from of the name of an oxygen-containing compound means that the oxygen atom has been substituted with a sulfur atom. General categories of sulfur-containing compounds include thiols (mercaptans), thiophenols, organic sulfides (thioethers), disulfides, thiocarboxyls, thioesters, sulfoxides, sulfonyls, sulfamides, sulfonic acids, sulfonates, and sulfates.

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**Selenium**

Selenium appears as a red or black amorphous solid, or a red or grey crystalline structure; the latter is the most stable. Selenium has properties very similar to those of sulfur; however, it is more metallic though it is still classified as a nonmetal. It acts as a semiconductor and therefore is often used in the manufacture of rectifiers, which are devices that convert alternating currents to direct currents. Selenium is also photoconductive, which means that in the presence of light the electrical conductivity of selenium increases. It is also used in the drums of laser printers and copiers. In addition, it has found increased use now that lead has been removed from plumbing brasses.

It is rare to find selenium in its elemental form in nature; it must typically be removed through a refining process, usually
involving copper. It is often found in soils and in plant tissues that have bioaccumulated the element. In large doses, the element is toxic; however, many animals require it as an essential micronutrient. Selenium atoms are found in the enzyme glutathione peroxidase, which destroys lipid-damaging peroxides. In the human body it is an essential cofactor in maintaining the function of the thyroid gland. In addition, some research has shown a correlation between selenium-deficient soils and an increased risk of contracting the HIV/AIDS virus.

Tellurium

Tellurium is the metalloid of the oxygen family, with a silvery white color and a metallic luster similar to that of tin at room temperature. Like selenium, it is also displays photoconductivity. Tellurium is an extremely rare element, and is most commonly found as a telluride of gold. It is often used in metallurgy in combination with copper, lead, and iron. In addition, it is used in solar panels and memory chips for computers. It is not toxic or carcinogenic; however, when humans are exposed to too much of it they develop a garlic-like smell on their breaths.

Polonium

Polonium is a very rare, radioactive metal. There are 33 different isotopes of the element and all of the isotopes are radioactive. It exists in a variety of states, and has two metallic allotropes. It dissolves easily into dilute acids. Polonium does not exist in nature in compounds, but it can form synthetic compounds in the laboratory. It is used as an alloy with beryllium to act as a neutron source for nuclear weapons.

Polonium is a highly toxic element. The radiation it emits makes it very dangerous to handle. It can be immediately lethal when applied at the correct dosage, or cause cancer if chronic exposure to the radiation occurs. Methods to treat humans who have been contaminated with polonium are still being researched, and it has been shown that chelation agents could possibly be used to decontaminate humans.

References


Problems

1. What properties increase down the oxygen family?
2. What element can form the most allotropes in the periodic table?
3. What is photoconductivity and which elements display this property?
4. Ozone (\(O_3\)) is a contributor to smog: True or False
5. How many electrons do elements of the Oxygen family have in their outermost shell?
6. What does the term "peroxide" refer to?
7. How many elements in the Oxygen Family are metals, and which one(s)?
8. What is the most common oxidation state for elements in the Oxygen Family?
9. What is the most abundant element by mass in the Earth's crust and in the human body?

Solutions

1. Melting point, boiling point, density, atomic radius, and ionic radius
2. Sulfur
3. Photoconductivity is when the electrical conductivity of an element increases in the presence of light. Both selenium and tellurium display this property.
4. True.
5. 6.
6. A compound that contains oxygen in the oxidation state of -1.
7. 1; Polonium.
8. -2.