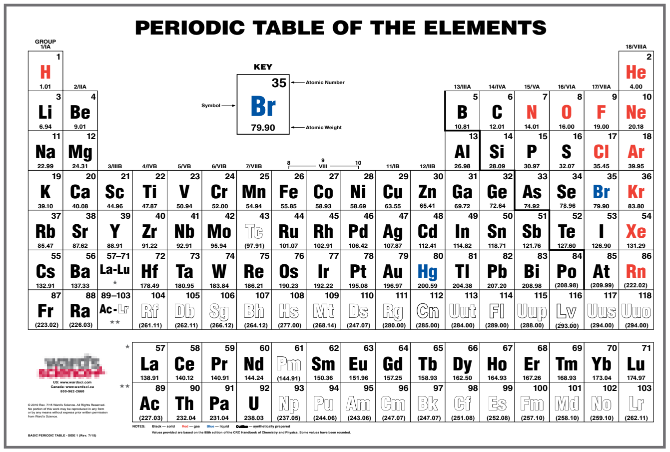
All About Elements:

Oxygen

boreal science

Ward's All About Elements Series
Building Real-World Connections to the Building Blocks of Chemistry



The periodic table of elements is an essential part of any chemistry classroom or science lab, but have you ever stopped to wonder about all of the amazing ways each element is used to create the world around us? Each of the trillions of substances in our universe can be tied back to just these 118 simple, yet powerful elements.

In our ***All About Elements*** series, we've brought together the most fascinating facts and figures about your favorite elements so students can explore their properties and uses in the real world and you can create chemistry connections in your classroom and beyond.

Look for a new featured element each month, plus limited-time savings on select hands-on materials to incorporate these element in your lessons.

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Fun Facts About... Oxygen

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O

15.999

1. Oxygen constitutes 21% of our atmosphere, nearly half the mass of the earth's crust and about two thirds of the human body. It is the third most abundant element in the universe after Helium and Carbon.

2. The oxygen that's produced as a result of photosynthesis is derived from the water absorbed by plants, not the carbon dioxide.

3. The ozone layer in the stratosphere, which protects us from UV radiation, is only an average of 3mm thick.

4. Under controlled conditions, the three most active metals (potassium, rubidium, and cesium) can react with oxygen to form oxides (M_2O), peroxides (M_2O_2) and superoxides (MO_2).

5. When water is boiled to kill bacteria, it drives out all dissolved gasses including oxygen. Therefore, aquatic life like goldfish and other freshwater fish cannot survive in water that's been previously boiled and then cooled. Water must be aerated before adding fish!

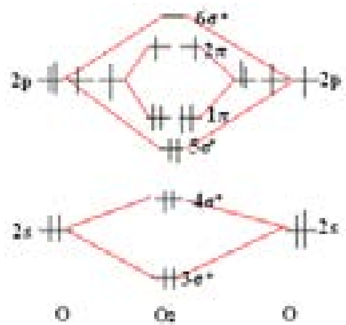
All About Oxygen:

Oxygen gas is essential for life on earth as we know it. It is the element that allows us to create the energy that enables us to live. Oxygen is the 8th element on the periodic table, located in Group VIB, with an electron configuration $1s^2 2s^2 2p^4$. It is classified as a non-metal, which means it reacts readily with metals, usually gaining two electrons to form metal oxides. These oxides, when dissolved in water, produce basic solutions. Oxygen can also react with other non-metals, sharing two of its valence electrons in covalent bonds. These non-metal oxides, such as sulfur dioxide, form acidic solutions.

An oxygen atom bonds with another oxygen atom to form the familiar oxygen gas, O_2, but it can also exist as the triatomic element, ozone, or O_3. At room temperature and pressure, oxygen, O_2, is a colorless, odorless gas. The structure for O_2 as usually written with a double bond between the oxygens. This however is incorrect! Molecular orbital calculations show us that O_2 has two degenerate antibonding orbitals each containing one electron. The O_2 molecule is therefore considered to be a diradical or triplet in its ground state.

Properties of Oxygen

Physical evidence for this diradical structure comes from the properties of liquid oxygen. It is blue in color and highly paramagnetic, both consistent with free radical structures.



Discovery and History

Scientists believe that oxygen has been in Earth's atmosphere for around 2.3 billion years. Life on Earth is thought to have started at least 3.5 billion years ago. The buildup of oxygen in the atmosphere may have been due to a decrease in geologic activity, which used up the oxygen produced by photosynthesis of some simple bacteria. Clearly oxygen was required for more complex life forms to develop.

The first awareness of oxygen gas by humans occurred in 1608 when the Dutch inventor, Cornelius Drebbel found that when he heated saltpeter, KNO_3, a gas was produced. The identity of this gas remained unknown until the 1770s when Joseph Priestly of England, Carl Wilhelm Scheele of Sweden, and Antoine-Laurent de Lavosier of France each worked with it. Lavosier discovered the role oxygen plays in respiration and combustion. He named the gas oxygen, which comes from the Greek "oxy" meaning acid and "gene" meaning producing.

Synthesis of Oxygen In the Lab

In the laboratory, there are a number of ways for oxygen to be produced. The decomposition of either potassium chlorate or potassium permanganate produces oxygen gas. The gas can be easily collected by water displacement.

$$2KClO_3 \text{ (400°C)} \longrightarrow 2KCl + 3O_2$$

$$2KMnO_4 \text{ (214°C)} \longrightarrow K_2MnO_4 + MnO_2 + O_2$$

The standard test for oxygen gas is to insert a glowing splint into a test tube containing the gas. If the splint bursts into flames, the gas is almost certainly oxygen. The decomposition of hydrogen peroxide is easily carried out in the lab, which also produces oxygen.

$$NaOCl(aq) + H_2O_2(aq) \longrightarrow NaCl(aq) + H_2O(l) + O_2(g)$$

Oxygen can also be prepared by the electrolysis of acidified water. The Hoffman electrolysis apparatus, which is shown below, demonstrates this in a laboratory setting.

An electric current passed through a diluted sulfuric acid solution will produce oxygen at the anode, by oxidation of water, and hydrogen at the cathode, by the reduction of water. The ratio of the oxygen to hydrogen produced is 1:2, which can clearly be seen using this device.

Commercial Production

Oxygen can be obtained from the atmosphere by the fractional distillation of air. Air is first cooled and liquefied. This liquid air is a mixture of liquid nitrogen, boiling point -196 ˚C, and liquid oxygen, boiling point -183˚C. The nitrogen, with its lower boiling point, evaporates first. Fractionation of the mixture will yield pure liquid oxygen after the nitrogen has evaporated. The oxygen is converted to gas and the gas is distributed as a compressed gas in high pressure cylinders.

Reactions of Oxygen

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Uses of Oxygen

Oxygen in the air is essential for respiration of most animals in order to produce energy. The oxygen atoms are returned to the atmosphere in the form of carbon dioxide. The largest commercial consumption of oxygen is in the steel industry where it is used in blast furnaces to increase the temperatures of the furnace. Oxygen is also used in electric arc furnaces used to melt scrap metal and in oxy-acetylene torches. Large quantities of oxygen are used in the manufacture of a number of chemicals. These include nitric acid, hydrogen peroxide, epoxyethane (ethylene oxide), used as antifreeze, and ethylene chloride, the precursor for polyvinyl chloride.

The oxygen tanks you see in the hospital provide an increased concentration of oxygen for patients who may have some difficulty breathing. Sparks near oxygen tanks are dangerous, not because oxygen is flammable, but because oxygen promotes burning. A small spark can become a big fire.

Oxygen is sparingly soluble in water, but the small quantity of dissolved oxygen is essential to the life of fish. Since gases are more soluble in cold water than in hot water, thermal pollution, or, the addition of hot water to streams and lakes, can cause fish to die due to a lack of oxygen. To prevent harm to aquatic life, industrial and power plants use billions of gallons of water to cool the water they use before releasing it back into lakes, rivers, and streams.

Peroxides and Superoxides

Oxygen's oxidation number in most compounds is -2. Interestingly, oxygen can also form compounds in which its oxidation number is -1 and even –½. In peroxides, the simplest of which is hydrogen peroxide, an O-O bond results in an oxidation number for oxygen of -1. When hydrogen peroxide decomposes it forms oxygen gas. Alkyl peroxides, R-O-O-R are often used as initiators for free radical reactions, including some polymerization reactions. The O-O bond breaks homolytically to form two radicals.

The most active metals, K, Rb, and Cs can react with oxygen to form superoxides. The oxygen in the $O2^{-1}$ anion in KO_2 has a formal oxidation number of –½ . When these superoxides dissolve in water, oxygen gas is produced. Potassium superoxide is used in gas masks worn for rescue work. Moisture in the breath converts the superoxide to the oxygen needed for respiration.

Tube of Toothpaste Demonstration (Catalytic Decomposition of Hydrogen Peroxide)
Ward's Item Number 2005600

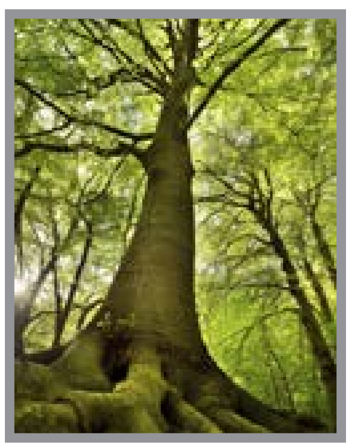
Oxygen and Photosynthesis

During photosynthesis, plants take in carbon dioxide to produce carbohydrates and eliminate oxygen gas. Red and blue light is absorbed by the green chlorophyll in the plants (green light is reflected) in order for the process to occur.

$$6CO_2 + 6H_2O \xrightarrow[\text{chlorophyll}]{\text{sunlight}} C_6H_{12}O_6 + 6O_2$$

It is often said that plants convert carbon dioxide to oxygen. This is not completely correct. The oxygen that plants produce and that we breathe actually comes from water. The first steps in the photosynthetic process are the absorption of light and the conversion of the light energy into chemical energy. The oxygen atoms in the water molecules are oxidized to form oxygen gas, which is eliminated. This only happens in daylight.

$$2H_2O \rightarrow 4e^- + 4H^+ + O_2$$



The high energy of the electrons produced is used to make the carbohydrates. Seventy five years ago scientists1 showed that when water containing oxygen-18 was "fed" to plants, all of the labeled oxygen ended up in the oxygen gas eliminated, and none was found in the carbohydrates produced. Therefore, it was concluded that carbohydrates come from carbon dioxide and oxygen comes from water.

1. Ruben, S., M. Randall, M. D. Kamen, and J. L. Hyde. (1941) "Heavy oxygen (O^{18}) as a tracer in the study of photosynthesis." Journal of the American Chemical Society, Vol. 63, pp. 877–879.Peroxides and Superoxides

Ozone

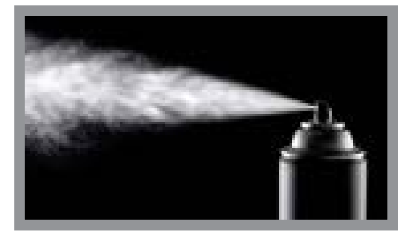
Ozone is an allotrope of oxygen that exists as three oxygen atoms bonded together to form O_3. It occurs naturally in the upper atmosphere and is formed in the lower atmosphere during electrical storms. At room temperature it is a pale blue gas with a pungent odor. It forms a dark blue liquid at -112°C and freezes to a purple solid at -193°C.

Ozone is an extremely reactive form of oxygen. It is second in strength to fluorine as an oxidizing agent. It is used commercially to bleach textiles and certain kinds of oils and is also a very effective germicide that can be used to sterilize air and water. In fact, ozone generators are available for hot tubs in order to keep them germ free. Unfortunately, ozone's high reactivity causes irritation of the nose and throat and decomposition of rubber and plastics.

Ozone in the stratosphere, the upper atmosphere, is essential for protecting us from harmful UV radiation. Most high energy radiation (<240nm) is absorbed by oxygen gas to produce ozone. However, UV radiation between 240nm and 290nm is not absorbed by oxygen and would be harmful to life on earth were it not absorbed by ozone.

$$2O_3 \underset{<240\text{nm}}{\overset{240\text{–}290\text{nm}}{\rightleftharpoons}} 3O_2$$

In the past, chlorofluorocarbons used as coolants, in spray cans, fire extinguishers and cleaning products were responsible for depleting the protective ozone layer, particularly over the north and south poles. This ozone layer has begun to be renewed because of government limitations on the use of these materials.



Too little there . . . Many popular consumer products like air conditioners and refrigerators involve CFCs or halons during either manufacture or use. Over time, these chemicals damage the earth's protective ozone layer.

Too much here . . . Cars, trucks, power plants and factories all emit air pollutino that forms ground-level ozone, a primary component of smog.

On the other hand, ozone in the lower atmosphere is harmful to human health. It damages vegetation and corrodes many materials. Ozone is an important ingredient of smog. Vehicles and some manufacturing plants emit air pollution that forms ozone. Inside the hot cylinders of internal combustion engines, nitrogen and oxygen can react to form nitrogen oxide, NO (equation 1). The NO reacts with oxygen in the air to form NO_2 (eqation 2). In the presence of bright light, the NO_2 dissociates to form the oxygen radical (equation 3), which can react with more O_2 to form ozone (equation 4).

1 $N_2(g) + O_2(g) \rightarrow 2NO(g)$

2 $2\,NO(g) + O_2(g) \rightarrow 2\,NO_2(g)$

3 $NO_2(g) + light \rightarrow NO(g) + O(g)$

4 $O(g) + O_2(g) \rightarrow O_3(g)$

The Environmental Protection Agency implements programs to reduce the emission of noxious gases from vehicles, power plants and manufacturing sites and thereby limit harmful ozone.

Teach All About Oxygen with these Hands-on Materials:

Save 13% on these items through September 2016 with promo code EOM16

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Click item or search by item number to see complete product details and current pricing available at boreal.com.

Determination of Dissolved Oxygen Kit

Determination of Dissolved Oxygen kit, 40 tests, Kit Contents: 4 Plastic Pipettes, 3 Reaction Vessel, 3 Collection Bottle, 2 Titrator, 30mL Manganese Chloride Reagent 30mL Alkaline Iodide Reagent, 30mL 50% Sulfuric Acid, 60mL Sodium Thiosulfate Titrant

Item Number: 470146-436

Ward's® Photosynthesis Demonstration

Simple Yet Versatile, For A Variety Of Investigations

- Demonstrate Photosynthesis On An Overhead Or Document Camera
- Works With Aquatic Or Terrestrial Plants

Easily demonstrate quantitative examples of photosynthesis and various environmental effects on plants with WARD'S photosynthesis apparatus. The variety of suggested experiments work with either aquatic plants or terrestrial plants. You can change the variables affecting photosynthesis and measure the rate of oxygen emitted as a byproduct, or test the influence of light intensity and wavelength, carbon dioxide and oxygen concentration in water, and other environmental factors. You can even place the apparatus on the overhead projector so the entire class can see the demonstrations. The model comes with a chamber, set of three color filters, set of three light-limiting bars, and instructions with suggested activities that can be performed with the apparatus.

Item Number: 470300-688

Ward's® What's Up With the Ozone Lab Activity

Test Your Local Area for Ozone Conditions

- Designed for AP level students
- Practice preparing test strips
- Includes a teacher's guide

The differentiation of ozone levels within the same general vicinity is explored in this AP level lab. Students prepare their own test strips and carry out tests for tropospheric ozone pollution. They then analyze the results for local variation and possible impact on human health. Includes a teacher's guide, student copymasters, and materials for six setups.

Item Number: 360913

Hydrogen Peroxide

CAS Number: 7722-84-1
Formula Weight: Mixture
Formula: Mixture
Density (g/mL): Approximately 1.0
Boiling Point (°C): Approximately 100
Freezing Point (°C): Approximately 0
Solubility: Water and Alcohol
Synonyms: Hydrogen Dioxide
Shelf Life (months): 12
Storage: White/Green
Please Note: This product is designed for educational and teaching laboratories, and no certificate of analysis is available..

Item Number: 470301-288

Hoffman Electrolysis Apparatus

The Hoffman Electrolysis Apparatus is used for the qualitative and quantitative study of the electrolytic decomposition of electrolytes such as water and hydrochloric acid. Tubes are 50mm each. Included platinum electrodes are also sold separately. Includes activity guide. Contents: 1 Support Stand, 1 Burette Clamp, 1 Extension Clamp, 1 Bosshead Clamp, 1 Pair of Platinum Electrodes, 1 Pair of Carbon Electrodes, 1 Activity guide.

Item Number: 470213-364

Ward's® Effects of Solar UV Radiation on Cells Lab Activity

Dramatic Results Mimic Effects of Sun on Living Tissue

- Demonstrate the effects of solar radiation
- Apply concepts to themselves
- Estimated class/lab time required: 45 minutes

Do sunscreens and sunglasses really work to block damaging UV rays? Your class treats the lid of a Petri dish containing a sun-sensitive yeast strain with sunscreen or covers part with sunglasses, leaving part exposed to ultraviolet radiation from the sun. After incubating the plate, students can gauge the effects of the sun on the yeast cells, applying their findings to humans as well. Other simple experiments explore additional factors such as the angle of the sun, ozone depletion, and air pollution. Includes enough materials for 24 students.

Note: Coupon included for perishable materials. Redeem by phone or e-mail.

Item Number: 853519

Content Contributed by Joe Simson

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