Chemicals in Our Breathing Space

Overview

In this activity, students will consider the chemical make-up of some of the substances in Earth's atmosphere that are important to the study of climate change. Students will construct simple molecular models of selected chemical agents.

Background

It is virtually impossible to discuss climate change, global warming, and air pollution without reference to specific chemical materials in our atmosphere. Take the examples of *carbon dioxide* and *methane.* Their build-up in the atmosphere, resulting from human activity over a period of many decades, contributes to the enhanced greenhouse effect that many scientists believe is a cause of global warming. While there are many other so-called greenhouse gases being emitted by human activity, carbon dioxide and methane are of particular concern because these emissions are so abundant. *Water vapor* is another important greenhouse gas, but its occurrence in the atmosphere is due mainly to natural processes.

Smog is a hazy form of air pollution caused by chemical interactions in the lower atmosphere. With sufficient heat and sunlight, *Nitrogen oxides (NOx)* and *volatile organic compounds (VOCs)* react to form ground-level *ozone*, the main component of smog. The NOx compounds are produced by automobiles and other combustion sources. Although VOCs are present in nature, they also occur as a result of industrial and other human activities. A commonly known VOC is *benzene*, the sweet-smelling major component of gasoline.

What exactly are these chemical agents made of, and how might they appear if you had a microscope powerful enough to see their atomic structures?

Atoms, Molecules, and Chemical Bonds

Atoms and molecules are the basic building blocks of all matter. Individual atoms can combine to form molecules of more than one atom, and some molecules contain different types of atoms. When only one type of atom is present in a molecule, the substance is an element. An element is any of the 116 known substances (of which 92 occur naturally) that cannot be separated into simpler substances. An example is *oxygen*, which exists in a free state as a gas. A molecule of oxygen contains exactly two oxygen atoms bound together; it therefore has the chemical formula 0_2.

When more than one type of atom (element) is present in a molecule, that substance is called a compound. An example of a compound is carbon dioxide, which has the chemical formula $C0_2$. As the formula suggests, a molecule of carbon dioxide contains exactly one atom of carbon and two atoms of oxygen.

The atoms in molecules are held together by chemical bonds. While there are different types of chemical bonds, all of the substances described in these few pages are gases, whose atoms are held together by covalent bonds. A covalent bond is one in which electrons are shared between two atoms.

Covalent bonds may be single, double, or triple, depending on the number of electrons involved:

- A single bond occurs when two adjacent atoms share a pair of electrons.
- A double bond is the sharing of two pairs of electrons.
- A triple bond is the sharing of three pairs of electrons.

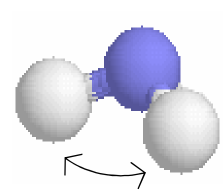
In general, double bonds are stronger than single bonds, while triple bonds are stronger still.

Any time atoms combine (or recombine) to form compounds, there is an exchange of energy involving electrons. In any chemical reaction, bonds are broken and new bonds are formed. Some reactions require an input of energy to break bonds before new substances can be formed — for example, a spark when fuel is combusted in an automobile engine. Energy for chemical reactions in our atmosphere may be obtained from heat, sunlight, or even lightning. Ultraviolet radiation from the sun is the energy source that plays a part in the formation and destruction of ozone in the stratosphere.

Student Activity: Constructing Molecular Models

Scientists have created different types of models to physically represent molecular structures. Some molecules are very large and complex. The models help scientists to understand the appearance and behavior of chemicals and provide insight into the ways compounds are formed and how new substances might be synthesized. However, the molecules selected for this activity are relatively simple chemical structures that can easily be represented by 2- and 3-dimensional models. Two useful model types are the structural formula and the ball-and-stick model.

Take the example of water vapor, which can be represented as follows:

Chemical Name and Formula	Physical Description	2-D Structural Formula	3-D Ball-and-Stick Model
Water H_2O	Triangular geometry; 2 hydrogen atoms single-bonded to one oxygen atom; $\alpha = 104.5^o$	O — H / H	 $\alpha = 104.5^o$

In the structural formula for water, the connecting lines between hydrogen and oxygen signify single bonds. If present, a double bond would be indicated by a double line, and a triple bond would be indicated by a triple line. In ball-and-stick models, for the sake of simplicity, a single stick is sometimes used to represent any kind of atomic bond. Note that each element is assigned its own color.

<u>Materials</u>: Toothpicks; gumdrops or 1-inch styrofoam balls (a different color to represent each of the following elements: hydrogen, oxygen, carbon, and nitrogen); protractor; colored pencils

<u>Procedure</u>

1. Refer to the attached chart. Listed are several chemical substances of interest to scientists in the study of climate change and air pollution. Use the chemical formula and physical description of each substance to create the missing 2-D and 3-D molecular models. Refer to the completed examples for help.

2. In drawing the 2-dimensional structural models, use one, two, or three short lines between atoms to indicate whether bonds are single, double, or triple. Where angles between atoms are given, use a protractor to approximate the correct angles in your drawings. (Do not be too concerned with the drawing of methane — it is not possible to represent the angles accurately in 2 dimensions.)

3. Create 3-dimensional models using colored styrofoam balls or gumdrops held together by toothpicks. Use one, two, or three toothpicks between atoms to indicate whether bonds are single, double, or triple. Be consistent in the choice of colors. For example, if red is selected to represent carbon, all carbon atoms should be red. Use a protractor to approximate the correct angles between atoms.

4. When you have completed the 2-D and 3-D models, check the answer key. Make any necessary corrections.

5. Complete the last column in the table by making a color drawing of each 3-D model.

Extension Activity

Visit these websites to explore virtual libraries of molecular models:

http://www.molecules.org/
http://www.nyu.edu/pages/mathmol/library/
http://www.faidherbe.org/site/cours/dupuis/banque.htm

Visit these websites to learn more about ozone and to see some cool videos:

http://www.epa.gov/oar/oaqps/gooduphigh/
http://svs.gsfc.nasa.gov/stories/UARS/ozone_models.html

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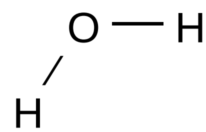
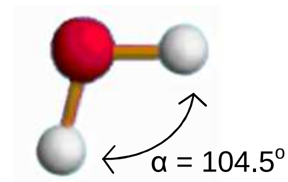
Water H_2O *(Greenhouse Gas)*	Triangular geometry; two hydrogen atoms single-bonded to one oxygen atom; $\alpha = 104.5^o$		
Carbon Dioxide CO_2 *(Greenhouse Gas)*	Linear geometry; two oxygen atoms double-bonded to one central carbon atom		
Methane CH_4 *(Greenhouse Gas)*	Tetrahedral geometry; four hydrogen atoms spaced evenly around and single-bonded to one carbon atom; $\alpha = 109.5^o$		
Nitrous Oxide N_2O *(Greenhouse Gas)*	Linear geometry; two nitrogen atoms tripled-bonded together with a single bond to one oxygen atom; (one of two possible configurations)		
Ozone O_3 *(May be either "good" or "bad")*	Triangular geometry; three oxygen atoms with one single bond and one double bond; $\alpha = 116.8^o$		
Benzene C_6H_6 *(One of the major VOCs)*	Six carbon atoms forming a hexagonal ring with alternating single and double bonds; one hydrogen atom single-bonded to each carbon atom around the outside		

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Teachers' Notes

<u>Objectives</u>: Students will consider the chemical make-up of some of the substances in Earth's atmosphere that are important to the study of climate change. Students will construct simple molecular models of selected chemical agents.

<u>Grade Level</u>: Middle/High

<u>NSES</u>: B4, B7, B8, B9

<u>NHSCF</u>: 5b, 6a, 6c

<u>Key Concepts</u>

An *atom* is the smallest particle of matter that retains the identity of if its chemical element. Each atom has a nucleus composed of neutrons and positively charged protons. The nucleus is surrounded by negatively charged electrons.

An *ion* is an atom that has gained or lost one or more electrons; consequently, ions are positively or negatively charged particles.

An *element* is any of 116 presently known substances (including 92 occurring naturally) that cannot be broken down into simpler substances. An atom is the smallest possible unit of an element. Hydrogen, carbon, nitrogen, oxygen, sulfur, and iron are examples of elements. The elements have been classified into the familiar Periodic Table.

A *compound* is a substance composed of atoms or ions of two or more elements. The constituent atoms or ions in a compound are bound together in fixed proportions. Water, carbon dioxide, ammonia, and methane are examples of compounds.

A *molecule* is the smallest particle of an element or compound that can exist independently in stable form. The number of atoms in a molecule can range from one to thousands. A single molecule of helium contains just one atom. Many common substances contain only a few atoms, such as oxygen and nitrogen (two each), water and carbon dioxide (three each), and ammonia (four). Organic molecules contain at least several atoms. They begin with the simplest, which is methane (five), include aromatic compounds such as benzene (twelve), and continue with far more complex substances such as polymers and proteins.

Different models have evolved to represent molecules in one, two, or three dimensions. A molecule's chemical formula can be thought of as a simple one-dimensional model, using only alphabetic and numeric symbols to represent a substance: H_2 (hydrogen gas), NH_3 (ammonia), CH_3OH (methanol) are a few basic examples. The structural formula uses only letter symbols, but in two dimensions. This arrangement makes it possible to show where the bonds between atoms occur and whether those bonds are single, double, or triple covalent bonds. The 3-D ball-and stick model provides still further information by depicting the locations of atoms in three-dimensional space. (The angle formed by three adjacent atoms is designated by the symbol α.)

The geometric models in the student activity are not the only ways to represent molecular structures, but they are effective in describing the important concepts. Students might be mislead into believing that molecules would actually look like balls-on-sticks if they could be seen. It is helpful to remind students that atomic and molecular models are only conceptual representations of exceedingly small physical structures.

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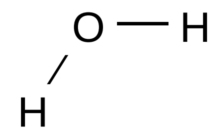
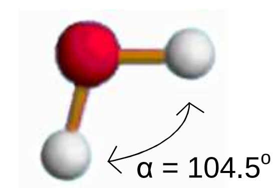
Water H_2O *(Greenhouse Gas)*	Triangular geometry; two hydrogen atoms single-bonded to one oxygen atom; $\alpha = 104.5^o$		
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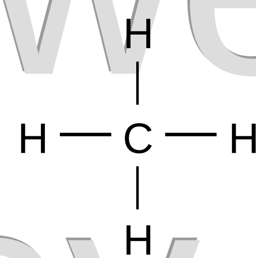
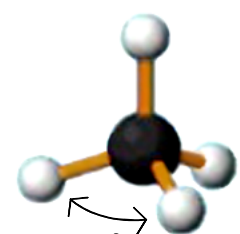
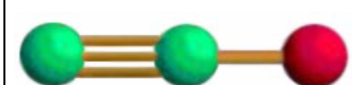
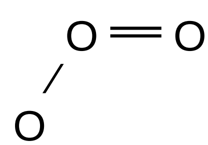
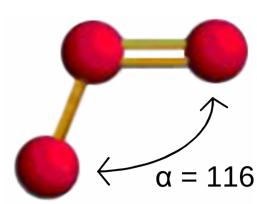
Methane CH_4 *(Greenhouse Gas)*	Tetrahedral geometry; four hydrogen atoms spaced evenly around and single-bonded to one carbon atom; $\alpha = 109.5^o$		
Nitrous Oxide N_2O *(Greenhouse Gas)*	Linear geometry; two nitrogen atoms tripled-bonded together with a single bond to one oxygen atom; (one of two possible configurations)		
Ozone O_3 *(May be either "good" or "bad")*	Triangular geometry; three oxygen atoms with one single bond and one double bond; $\alpha = 116.8^o$		
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