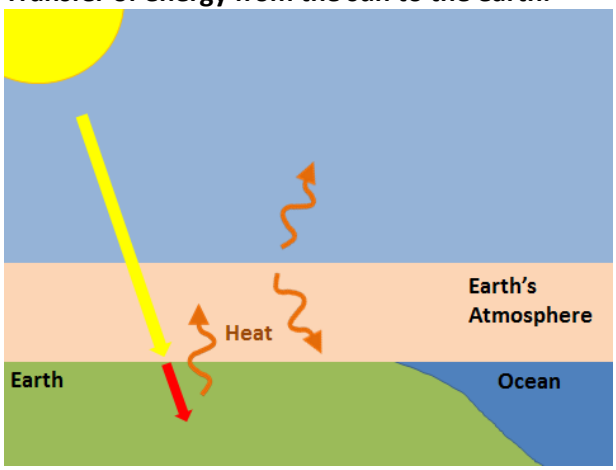
What makes a gas a greenhouse gas?

Overview

Solar energy absorbed by the Earth's surface is re-emitted as heat. Some of this heat is trapped in the atmosphere by greenhouse gases. Without these greenhouse gases, the average temperature of the Earth would be near 0 ^{o}F (-18 ^{o}C), instead of 59 ^{o}F (15 ^{o}C). Some gases of the atmosphere have this warming effect, while others do not.

In this hands-on, guided-inquiry learning activity, students will learn the structural features of greenhouse gases and non-greenhouse gases.

Transfer of energy from the sun to the earth.



Target audience: Middle, high-school, and entry-level college chemistry courses; works well in a classroom setting.

Prior knowledge

- A basic understanding of atomic and molecular theory
  - Atoms are made of protons (+ charge), neutrons (no charge), and electrons (- charge).
  - Atoms of the same type always have the same composition.
  - Atoms can share electrons (or "bond") and form molecules.
  - Molecules adapt different shapes: spherical, linear, bent, trigonal planar, etc.

Learning objectives

- Construct molecules of different composition and shapes
- Observe trends in molecular structure among greenhouse gases and non-greenhouse gases
- Develop the criteria for a gas to be a greenhouse gas
- Make predictions

Materials and supplies

- Molecular model kits (~1 per group of 2-3 students), containing balls representing atoms, wooden pegs for single bonds, springs for multiple bonds, and marbles for noble gases.
- Activity sheets (pages 5-6 of this document).

What makes a gas a greenhouse gas?

Instructions

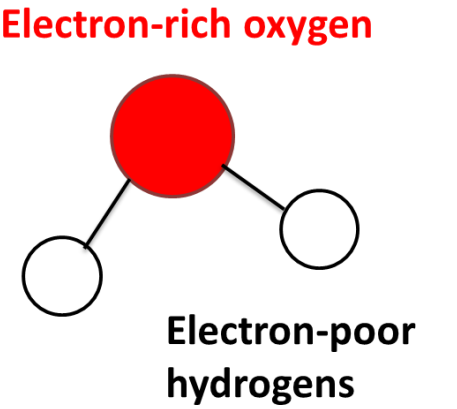
1. Open the model kits and identify the elements and bonds available to you.
2. Instruct students to follow the instructions on worksheet and construct four greenhouse gases and four non-greenhouse gases.
3. Then answer questions 1-4 on the worksheet.
4. In step 5, make predictions about whether gases are greenhouse gases or not.
5. Check your answers with your instructor. An answer key is provided.
6. After completion of the activity, the instructor should provide the following explanation of the phenomenon and pose discussion questions.

Safety Notes: This activity does not involve any chemicals or physical hazards.

Explanation: How the molecular structure relates to the trapping of energy emitted by Earth.

Greenhouse gases are molecules made up of more than one type of atom or contains three or more total atoms, giving it a shape that is neither linear nor spherical. Consequently, these molecules have uneven electron distributions. Water, for example, has an electron-rich oxygen atom and two electron-poor hydrogen atoms.

Model representation of water (H_2O).



Water can absorb infrared energy that is emitted by the earth, which causes oxygen-hydrogen bonds to stretch and bend. This motion requires energy to separate the positively and negatively charged regions of the molecule. As the molecules relax, they re-emit this energy in all directions, back towards the earth and to space.

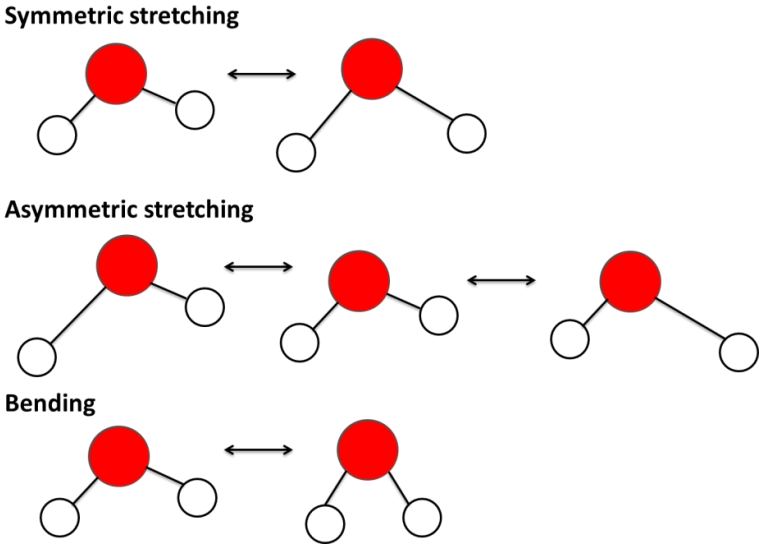
Greenhouse gases in the atmosphere create a blanket around the Earth, by keeping heat near to it.

The most abundant greenhouse gases in the Earth's atmosphere are water, carbon dioxide, and methane. These and other greenhouse gases make up less than 0.1% of the Earth's atmosphere.

Molecules made of one type of atom, like nitrogen, oxygen, and helium have even distributions of electrons. Importantly, there are no regions of the molecule with excess positive or negative charge. Consequently, these non-greenhouse gases do not trap energy re-emitted by the earth's surface. Non-greenhouse gases make up 99.9% of the earth's atmosphere.

What makes a gas a greenhouse gas?

Vibrations of the water molecule.

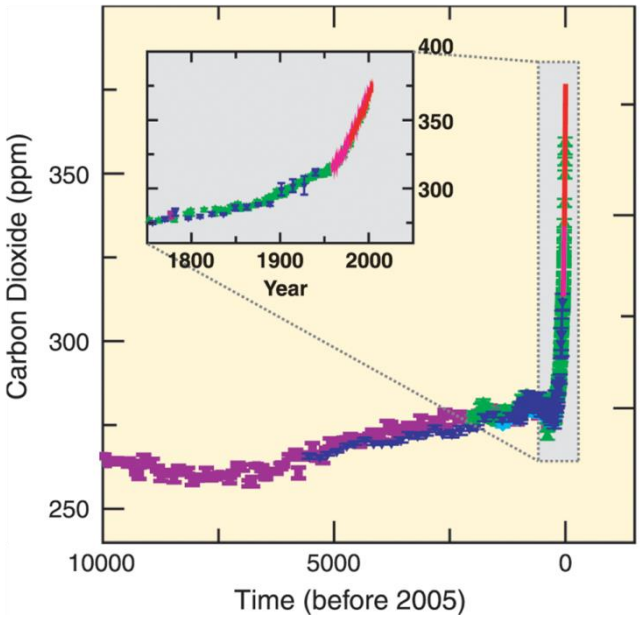


Discussion questions

1. Using the graph to the right, answer the following questions:
   a. What was the concentration of carbon dioxide (CO_2) 10,000 years ago? in 1800? in 2000?
   b. How have the levels of CO_2 changed over these time periods?
   c. How has the rate of change of the CO_2 concentrations (the steepness of the line) changed over the last 200 years?

2. What do you think will happen if the concentrations of greenhouse gases in the atmosphere increase?

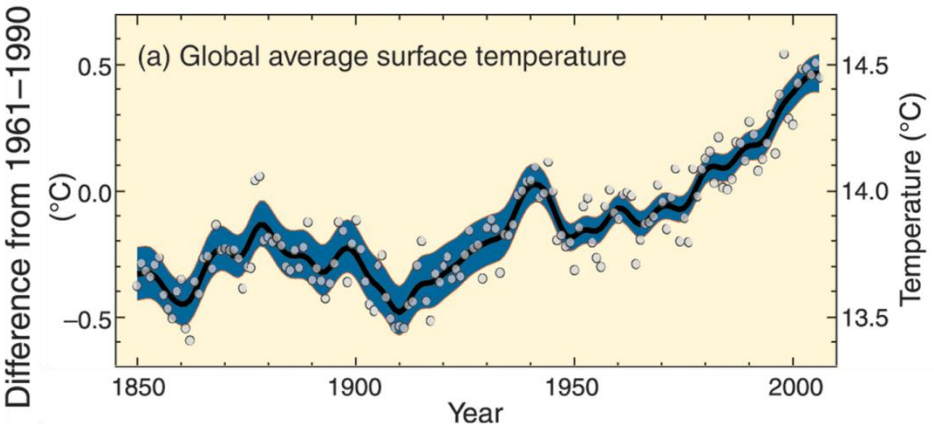
Historic carbon dioxide concentrations (IPCC 2014).



What makes a gas a greenhouse gas?

3. How has the temperature of the earth changed over the last forty years?

Trends in global surface temperature (IPCC 2014).



4. What are the major sources of greenhouse gases to the atmosphere?
5. What can you do to reduce your emissions of greenhouse gases?

References

ACS, 2012. ACS Climate Science Toolkit. (http://www.acs.org/content/acs/en/climatescience)

Intergovernmental Panel on Climate Change (IPCC), Fifth Assessment Report (http://www.ipcc.ch/report/ar5/index.shtml).

What makes a gas a greenhouse gas?

Name:_____

Model kits contain wooden balls, each color representing a different atom and wooden pegs or springs, for multiple bonds.

Instructions:

1. *Always turn springs clockwise when assembling or dismantling*
2. A single bond is represented by one spring, a double bond by two springs, and a triple bond by three springs.
3. Construct 4 non-greenhouse gas and 4 greenhouse gas molecules. Separate them into two piles.

Element	Symbol	Color
Carbon	C	Black
Nitrogen	N	Orange
Hydrogen	H	White
Oxygen	O	Yellow
Chlorine	Cl	Green
Noble gases	He, Ne	Marbles

Non-greenhouse gases

Nitrogen	**N_2**	2 orange, 3 springs	Connect the N atoms with a triple bond
Oxygen	**O_2**	2 yellow, 2 springs	Connect the O atoms with a double bond
Argon	**Ar**	1 marble	Argon is a noble gas, it does not form bonds
Neon	**Ne**	1 marble	Neon is a noble gas, it does not form bonds
Helium	**He**	1 marble	Helium is a noble gas, it does not form bonds

Greenhouse gases

Carbon monoxide	**CO**	1 black, 1 yellow, 3 springs	Connect the C and O with a triple bond
Ozone	**O_3**	3 yellow, 3 springs	Connect two O with a double bond, then add O with a single bond
Methane	**CH_4**	1 black, 4 white, 4 springs	Connect each H to C with a single bond
Ammonia	**NH_3**	1 orange, 3 white, 3 springs	Connect each H to N with a single bond
Water	**H_2O**	1 yellow, 2 white, 2 springs	Connect each H to O with a single bond
Nitric oxide	**NO**	1 orange, 1 yellow, 2 springs	Connect the N and O with a double bond
Nitrogen dioxide	**NO_2**	1 orange, 2 yellow, 3 springs	Connect two O atoms to the central N with one single bond and one double bond
Nitrous Oxide	**N_2O**	2 orange, 1 yellow, 4 springs	Connect the two N with a triple bond and the O to an N with a single bond
Carbon tetrachloride	**CCl_4**	1 black, 4 green, 4 springs	Connect each chorine atom to the central C with single bonds
Chloroform	**$CHCl_3$**	1 black, 1 white, 3 green, 4 springs	Connect each chlorine and hydrogen atom to the central C with a single bond

What makes a gas a greenhouse gas?

4. After you have at least 4 models in each pile, consider the following questions…

- How many total atoms are present in (circle your answers)

  …non-greenhouse gases? 1 2 3 4 5 ≤

  …greenhouse gases? 1 2 3 4 5 ≤

- How many *types* of atoms are found in…

  …non-greenhouse gases? 1 2 3 4 5≤

  …greenhouse gases? 1 2 3 4 5≤

- Sketch the shapes of the molecules in each group:

  Greenhouse gases Non-greenhouse gases

5. Using these observations, summarize the criteria for a gas to be a **non-greenhouse gas**:

Greenhouse gases, on the other hand, are the gases that do *not* meet the criteria of a non-greenhouse gas.

6. Predict whether the following gases are greenhouse gases. Circle your answer in the table below and state your reasoning.

Gas		**Shape**	**GHG ?**	**Rationale**
Carbon dioxide	CO_2	Linear	Y or N	
Hydrogen	H_2	Linear	Y or N	
Dichloromethane	CH_2Cl_2	Tetrahedral	Y or N	
Sulfur dioxide	SO_2	Bent	Y or N	
Krypton	Kr	Spherical	Y or N	

What makes a gas a greenhouse gas? Answer key

4. After you have at least 4 models in each pile, consider the following questions…
   - What numbers of atoms are found in… (circle your answers)
     …non-greenhouse gases? 1 2 3 4 5 ≤
     …greenhouse gases? 1 2 3 4 5 ≤
   - How many *types* of atoms are found in…
     …non-greenhouse gases? 1 2 3 4 5≤
     …greenhouse gases? 1 2 3 4 5≤ (Note the ozone case)
   - Sketch the shape of moleucles in each group

     Greenhouse gases: Linear, bent, trigonal planar, trigonal bipyramidal, tetrahedral, etc.

     Non-greenhouse gases: Spherical or linear

5. Using these observations, summarize the criteria for a gas to be a non-greenhouse gas:
   Non greenhouse gases are made of 1 atom (spherical), or 2 atoms that are identical (linear).
   Greenhouse gases, on the other hand, are the gases that do *not* meet the criteria of a non-greenhouse gas. They contain two or more types of atoms (usual case). Or contain 3 or more total atoms, taking on a non-spherical or non-linear shape (includes ozone case).

6. Predict whether the following gases are greenhouse gases. Circle your answer in the table below and state your reasoning.

Gas		Shape	GHG ?	Rationale
Carbon dioxide	CO_2	Linear	Y	It contains three atoms and more than one type of atom.
Hydrogen	H_2	Linear	N	It contains 2 atoms that are identical and is linear.
Dichloromethane	CH_2Cl_2	Tetrahedral	Y	It contains five atoms and three different types of atom
Sulfur dioxide	SO_2	Bent	Y	It contains three atoms and two different types of atoms.
Krypton	Kr	Spherical	N	It contains only 1 atom and is spherical.