

## Greenhouse Gases and Atmospheric Warming

### Learning Goals

1. Explain how the Earth's temperature is affected by gases that absorb IR radiation.
2. Explain how polar molecules such as  $\text{H}_2\text{O}$  can absorb IR radiation, causing them to vibrate in a way that changes their dipole moment.
3. Explain how nonpolar molecules such as  $\text{CO}_2$  and  $\text{CH}_4$  can absorb IR radiation, causing them to vibrate in a way that produces a temporary dipole moment.
4. Explain why the most abundant atmospheric gases ( $\text{N}_2$ ,  $\text{O}_2$ , Ar) are not greenhouse gases.
5. Explain the source of the major greenhouse gases ( $\text{H}_2\text{O}$ ,  $\text{CO}_2$ , and  $\text{CH}_4$ ).



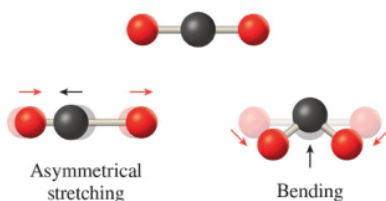
### Environmental Aspects

#### *Polarity and The Greenhouse Effect*

The greenhouse effect\* is a natural phenomenon that is largely responsible for Earth being hospitably warm. Sunlight warms Earth's surface, and some of that thermal energy is radiated back toward space in the form of infrared

(IR) radiation. Much of this energy escapes our atmosphere, but some is absorbed by molecules in the air and is then re-emitted in all directions—including back toward Earth's surface. This causes warming of the atmosphere, specifically the *troposphere*. According to the National Aeronautics and Space Administration (NASA), without the greenhouse effect, the average temperature here on Earth would be too cold for there to be any liquid water; and life, as we know it, would not exist.

For a molecule to absorb IR radiation, it must be able to undergo a change in dipole moment. But, a molecule need not *be* polar to do this. The best known of the so-called greenhouse gases,  $\text{CO}_2$ , is a nonpolar molecule. Upon absorption of IR radiation, though, molecular vibrations cause it to have a *temporary* dipole.  $\text{CO}_2$  and two of its vibrational modes that cause a change in its dipole moment are shown here.



$\text{CH}_4$  is another greenhouse gas that is nonpolar, but that has vibrational modes that cause a dipole-moment change. Most of our atmosphere is

$\text{N}_2$  and

$\text{O}_2$ . Homonuclear diatomic molecules such as these do not have vibrational modes that cause a dipole-moment change. Therefore, they do not absorb IR radiation and do not contribute to the greenhouse effect.

\*The *enhanced* greenhouse effect refers to excess atmospheric warming due to anthropogenically increased concentrations of greenhouse gases, such as  $\text{CO}_2$  and  $\text{CH}_4$ .

Electromagnetic radiation from the sun is what is primarily responsible for the earth's temperature. Without an atmosphere the average temperature of the earth would be  $-18^{\circ}\text{C}$ . The earth's atmosphere contains heat trapping gases known as greenhouse gases that results in the average temperature to be  $15^{\circ}\text{C}$ . Consequently, the earth is not a frozen snowball, but has liquid water that makes it hospitable to life as we know it. Dry air is 78%  $\text{N}_2$ , 21%  $\text{O}_2$ , 0.9% Ar with trace amounts of  $\text{CO}_2$  (0.04%),  $\text{CH}_4$  (0.0002%), and other gases. The real atmosphere has varying amounts of  $\text{H}_2\text{O}$  depending on the temperature and humid.  $\text{H}_2\text{O}$ ,  $\text{CO}_2$ , and  $\text{CH}_4$  are the original natural greenhouse gases. Water is in the atmosphere from evaporated bodies of water. Carbon dioxide comes from respiration, geothermal outgassing (volcanos and geysers) and forest fires. Methane comes from methane producing organisms. A warmed earth emits radiation in the IR region of the electromagnetic spectrum. This IR radiation is absorbed when there is a change in the molecular dipole (see the explanation in the text box). Water is a polar molecule, but  $\text{CO}_2$  with a symmetrical linear shape and  $\text{CH}_4$  with a symmetrical tetrahedral shape are non-polar. But these molecules undergo vibrations that produce temporary dipoles when they vibrate. See the animations of  $\text{H}_2\text{O}$ ,  $\text{CO}_2$ , and  $\text{CH}_4$  vibrations at the following website.

[https://chemapps.colostate.edu/chem103/molecules/global\\_warming/h2oNjism.html](https://chemapps.colostate.edu/chem103/molecules/global_warming/h2oNjism.html)

[https://chemapps.colostate.edu/chem103/molecules/global\\_warming/co2Njism.html](https://chemapps.colostate.edu/chem103/molecules/global_warming/co2Njism.html)

[https://chemapps.colostate.edu/chem103/molecules/global\\_warming/methaneNjism.html](https://chemapps.colostate.edu/chem103/molecules/global_warming/methaneNjism.html)

Greenhouse gases absorb energy from IR radiation and transmit energy to  $\text{N}_2$ ,  $\text{O}_2$ , and Ar increasing their kinetic energy and thus the temperature.  $\text{N}_2$  and  $\text{O}_2$  are non-polar diatomics that can never have a dipole caused by vibrations.

The *enhanced* greenhouse effect is due to *anthropogenic (human-caused)* greenhouse gases and this leads to average temperatures above  $15^{\circ}\text{C}$ . Such temperature increases lead to climate change, sea level rise, drought, stronger hurricanes, wildfires, etc.

Fossil fuel burning and cement production are anthropogenic sources of  $\text{CO}_2$ . Leaks from natural gas extraction and transport and high intensity beef agriculture are anthropogenic sources of  $\text{CH}_4$ .

$\text{N}_2\text{O}$  (produced from fertilizers),  $\text{SF}_6$  (a gaseous insulator used in electricity industry),  $\text{O}_3$  (a component of urban smog), HCFC's (replacement for stratospheric ozone destroying CFC's used in air conditioners and refrigerators) are additional anthropogenic greenhouse gases.

The most direct solution to the enhanced greenhouse gas problem is reduce the concentration of these molecules in the atmosphere. This is primarily done by reducing emissions. Some scientists are also developing techniques for removing such molecules from the atmosphere. Adapting to a warmer planet is also possible but is a less desirable solution.

## Study Questions

1. What are the three major greenhouse gases and where do they come from?
2. Why kind of electromagnetic radiation is absorbed by greenhouse gases?
3. What happens to greenhouse gas molecules when they absorb light emitted from the earth?
4. What happens to the atmosphere and the surface of the earth as a result?
5. What are some of the solutions to dangerous warming caused by the enhanced greenhouse effect.