**IR Spectroscopy and Greenhouse Gases**

Retinas. Microwave ovens. Night vision goggles. They all rely on the interaction of electromagnetic radiation with matter. The principle source of electromagnetic radiation is the sun. Radiation moving at the speed of light leaves the sun and travels toward Earth. These photons come in a range of wavelengths, allowing them to interact with matter in many ways depending on their energy. Wavelengths in the visible portion of the spectrum reflect off of objects and hit the retinas in our eyes, sending a signal to our brains that registers as a specific color. Water molecules flip and rotate as they absorb microwave radiation, creating frictional energy that raises the temperature of the food. Everything on Earth’s surface emits infrared radiation that can be detected and amplified with night vision goggles.

Spectroscopy is the study of interactions between electromagnetic radiation and matter to reveal useful information about its structure. Recall the frequency-energy relationship: the higher the frequency the more energetic the wave. Ultraviolet and visible radiation have enough energy to bump an electron from ground state to a new, higher energy level. When those excited electrons return to the ground state they release energy as photons of light whose wavelengths can be detected and measured. Absorption and emission spectra in the UV-visible range provide characteristic patterns, much like a barcode, that help researchers identify the elements in a given sample.

Infrared radiation, of lower energy than UV-vis, interacts with the bonds of molecules that vibrate, stretch, and rotate. The bonds in molecules are in constant vibrational motion and the surrounding atoms in the molecule influence each of these motions. These bond motions absorb some frequencies that fall within the IR region of the spectrum, while transmitting others. This phenomenon allows us to correlate specific absorption patterns with particular bond arrangements. By cataloging the IR spectrums of different bond combinations, chemists can use this data to identify the types of bonds present in a molecule. IR spectroscopy is a widely used analytical tool for the identification and confirmation of substances and applications can be found in almost all chemical fields, including atmospheric chemistry.

Earth is constantly bombarded by electromagnetic radiation from the sun. Much of the UV and visible radiation from the sun passes through the atmosphere heating up the land, water, and everything else on Earth’s surface. Those objects radiate thermal energy in the IR region of the spectrum back up into the atmosphere where it interacts with atmospheric gases. Gases that readily absorb IR radiation can capture that thermal energy and prevent it from returning to space. This capture of IR radiation in the atmosphere is what gives the atmosphere its greenhouse-like properties and why those gases involved in the capture are called greenhouse gases.

Purpose

In this activity you will examine IR spectra to identify which atmospheric gases are capable of absorbing IR radiation and explain why this property makes those gases contribute to a greenhouse effect in the atmosphere.

Pre-Lab Questions



Figure 1

Questions 1-5 refer to Figure 1.

1. According to Figure 1, what happens to the 6.6×1013 and 6.2×1013 Hz frequencies of IR radiation as they pass through the sample?
2. What value is measured on the y-axis? Explain the relationship between absorbance and transmittance.
3. What value is measured on the x-axis? How do its units relate to the units of wavelength? Based on the unit for the two values, suggest a mathematical relationship between these two quantities.
4. Identify which peaks on the graph correspond to the 6.6×1013 and 6.2×1013 Hz frequencies. Explain your reasoning.
5. Calculate the wavelength in nanometers of a wave whose wavenumber is 2200 cm-1. How does this value relate to the frequencies you assigned in question 4?
6. Vibrational movements of bonded atoms may be categorized as symmetrical stretching, asymmetrical stretching, and bending. Write the appropriate term for each motion shown in Figure 2.



Figure 2

Procedure

Study the following IR spectra and identify the wavenumber of the major absorption bands. Record the three greatest regions of absorption in Table 1.

     

 

  

Data and Observations

|  |  |  |  |
| --- | --- | --- | --- |
| Table 1  IR Absorption Bands of Atmospheric Gases | | | |
| Gaseous Components of the Atmosphere | Absorption Band  cm-1 | Absorption Band  cm-1 | Absorption Band  cm-1 |
| Nitrogen |  |  |  |
| Oxygen |  |  |  |
| Water |  |  |  |
| Argon |  |  |  |
| Carbon Dioxide |  |  |  |
| Neon |  |  |  |
| Helium |  |  |  |
| Methane |  |  |  |
| Krypton |  |  |  |
| Nitrous oxide |  |  |  |
| Hydrogen |  |  |  |
| Xenon |  |  |  |
| Ozone |  |  |  |
| Dichlorodifluoromethane |  |  |  |

Analysis and Conclusion Questions

1. Categorize the gases by writing their chemical formulas in the appropriate boxes below.

|  |  |
| --- | --- |
| Absorbs in the IR region of the spectrum | Does NOT absorb in the IR region of the spectrum |
|  |  |

1. In the table above, identify the group of gases that contribute to the greenhouse effect by drawing a circle around the set of formulas considered to be “greenhouse gases.” Defend your selection by developing a definition for a “greenhouse gas” using information from the introductory paragraphs.
2. A chemist runs an IR scan on two different unknown gas samples. Use the spectra from the lesson to identify which gases are present in each unknown. For each unknown gas, provide evidence that supports your claim.

 

1. The introduction describes interactions between the sun’s radiation and Earth’s atmosphere. Use the description provided in the introduction to draw a visual representation of the process that occurs as electromagnetic radiation travels from the sun to Earth and back into space.
2. Global warming is attributed to increasing levels of man-made greenhouse gases such as carbon dioxide and chlorofluorocarbons. Using what you have learned about these gases and their interaction with thermal IR radiation, explain why increasing levels of those gases in the atmosphere are associated with increasing global temperatures.
3. Suggest at least 3 specific ways that humans can help reduce greenhouse gas production and rank them in order of greatest potential impact. For your most impactful suggestion, assess the sociopolitical implications of implementing that suggestion.