Lesson Plan: Infrared Spectroscopy and the Greenhouse Gas Effect

Lesson plan idea contributed by Dr. Sharda Pasricha, Associate Professor, Sri Venkateswara College, University of Delhi

As an **undergraduate-level Organic Chemistry teacher**, you can use this set of computer-based tools to help you teach **infrared (IR) spectroscopy** and **the use of IR spectra to detect functional groups in organic molecules.**

The lesson plan will help students differentiate between IR active molecules and IR inactive molecules. It focuses on the behavior of molecules of gases such as CO_2 and water vapor when they interact with IR radiation and helps in explaining the greenhouse effect of the atmosphere.

Thus, the use of this lesson plan allows you to integrate the teaching of a climate science topic with a core topic in **Organic Chemistry**.

Use this lesson plan to help your students find answers to:

- What happens when a molecule absorbs IR light?
- What information do the diagnostic and fingerprint regions of the IR spectrum of a compound convey?
- What are the vibrational modes of carbon dioxide molecules?
- Discuss why carbon dioxide (CO_2), methane (CH_4), and water vapor are greenhouse gases while oxygen (O_2) and nitrogen (N_2) are not.

About the Lesson Plan

- **Grade Level:** **Undergraduate**

- **Discipline:** **Chemistry**

- **Topic(s) in Discipline:** **Infrared (IR) Spectroscopy, Molecular Vibration, Vibrational Modes, IR Active Molecule, IR Absorption and Greenhouse Gases, Greenhouse Effect, Diagnostic and Fingerprint Regions of Infrared (IR) Spectra, Stretching and Bending Modes of Vibration**

- **Climate Topic:** **Climate and the Atmosphere, The Greenhouse Effect**
- **Location:** **Global**
- **Access:** **Online**
- **Language(s):** **English**
- **Approximate Time Required:** **45-60 min**

1 Contents

1. A set of video micro-lectures (~20 min)

a) A video that introduces IR spectroscopy and the working of an IR spectrometer.
https://www.youtube.com/watch?v=DDTIJgIh86E

b) A video that explains how the functional groups of a molecule can be identified by examining its IR spectrum.
https://www.youtube.com/watch?v=n_tiHttsvYY

c) A video that describes the vibrational modes of polyatomic molecules and how these modes determine whether the molecules are IR inactive or IR active.
https://www.youtube.com/watch?v=T9tsnkO3z1Y

2. Micro-lecture and reading (~25 min)

A micro-lecture that explains why most IR active polyatomic gas molecules are greenhouse gases.

http://www.kaltura.com/index.php/extwidget/preview/partner_id/1090132/uiconf_id/20652192/entry_id/0_n9uzmhwk/embed/auto?

A reading that discusses the vibrational modes of water vapor and carbon dioxide (CO_2) molecules in detail and explains why these gases act as greenhouse gases.

http://forecast.uchicago.edu/chapter4.pdf (pg. 29-32)

3. Suggested questions/assignments for learning evaluation

- What happens when a molecule absorbs IR light?
- What information do the diagnostic and fingerprint regions of the IR spectrum of a compound convey?
- What are the vibrational modes of carbon dioxide molecules?
- Discuss why carbon dioxide (CO_2), methane ($CH_{4)}$, and water vapor are greenhouse gases while oxygen (O_2) and nitrogen (N_2) are not.

2 Step-by-step User Guide

Here is a step-by-step guide to using this lesson plan in the classroom/laboratory. We have suggested these steps as a possible plan of action. You may customize the lesson plan according to your preferences and requirements.

1. Introduce the topic through a series of micro–lectures

Introduce the topic of spectroscopy and explain how different types of spectroscopy are used to elucidate the structures of molecules of organic compounds. Use a series of micro-lectures developed by the Royal Society of Chemistry to

- introduce IR spectroscopy,

- explain the application of IR spectroscopy in organic chemistry to detect functional groups in molecules, and
- describe the vibrational modes of these molecules on absorption of IR light.

a) Use the micro-lecture "Infrared spectroscopy (IR)" available at https://www.youtube.com/watch?v=DDTIJgIh86E to explain what happens when a molecule is exposed to IR radiation. Explain that a molecule absorbs IR energy when the frequency of stretching or bending of the molecular bonds corresponds to that of the incident IR light. Use this video to explain the basic working of an IR spectrometer that is used to obtain the IR spectra for known/unknown molecules. Further, with the help of the video, briefly explain how the functional groups present in a molecule can be deduced by examining its IR spectrum.

b) Next, play the micro-lecture "Chemistry Vignettes: IR Spectroscopy" available at https://www.youtube.com/watch?v=n_tiHttsvYY. Discuss how the pattern of the IR radiation absorption spectrum can be used to determine the functional groups present in the molecule. Emphasize that every peak in the IR spectrum is characterized by its frequency, intensity, and shape of the band, and that these factors depend on the type of functional group present in the molecule. Further, use the video to describe the fingerprint region of the IR spectrum; this region can be used to identify an unknown organic molecule.

c) Play the video micro-lecture "Chemistry Vignettes: Vibrational Modes" available at https://www.youtube.com/watch?v=T9tsnkO3z1Y to describe the vibrational modes of polyatomic molecules. Explain that only some vibrational modes (those that lead to a fluctuating dipole) result in absorption of IR light energy. Introduce the terms "IR active molecules" and "IR inactive molecules" by using the CO_2 molecule as an example and describe its different modes of vibration.

2. Explore the topic further with a micro-lecture and an associated reading

Use a micro-lecture and associated reading from Prof. David Archer, the University of Chicago, to discuss the effects of IR absorption on gas molecules; further, explain vibrational modes and why certain atmospheric gases such as carbon dioxide (CO_2), water vapor, and methane (CH_4) act as greenhouse gases.

Play the video micro-lecture "Greenhouse Gases" available at http://www.kaltura.com/index.php/extwidget/preview/partner_id/1090132/uiconf_id/20652192/entry_id/0_n9uzmhwk/embed/auto? to describe the various modes of vibration in polyatomic gas molecules. Use the video to discuss the development of a charge imbalance (electrical dipole) in molecules due to the asymmetrical stretching or bending modes of vibration. Explain that this results in the absorption of heat energy from incident IR radiation in gas molecules such as carbon dioxide (CO_2), water vapor, and methane (CH_4); therefore, these gases trap the heat energy in the atmosphere and act as greenhouse gases.

Use the associated reading from Prof. David Archer's book "Global Warming: Understanding the Forecast", available at http://forecast.uchicago.edu/chapter4.pdf (pg. 29-32), for a detailed description of how chemical bonds respond to incident IR light. Explain that due to electrical dipole moments developed during molecular vibrations, some bonds absorb IR energy of specific frequencies. Use this reading to explain the various vibrational modes in polyatomic gas molecules such as water vapor and carbon dioxide (CO_2). Reiterate that the absorption of incident IR radiation by these gas molecules in certain vibrational modes makes them greenhouse gases.

3. Questions/Assignments

Use the tools and the concepts learned so far to discuss and determine answers to the following questions:

- What happens when a molecule absorbs IR light?
- What information do the diagnostic and fingerprint regions of the IR spectrum of a compound convey?
- What are the vibrational modes of carbon dioxide molecules?
- Discuss why carbon dioxide (CO_2), methane (CH_4), and water vapor are greenhouse gases while oxygen (O_2) and nitrogen (N_2) are not.

3 Learning Outcomes

The tools in this lesson plan will enable students to:

- identify the presence or absence of functional groups in an unknown organic compound and use IR spectroscopy as a tool for structural identification of organic compounds
- differentiate between an IR active mode of vibration and an IR inactive mode of vibration in a molecule
- explain why carbon dioxide is a greenhouse gas and why nitrogen and oxygen are not greenhouse gases
- discuss the relative global warming potentials of various greenhouse gases

4 Additional Resources

If you or your students would like to explore the topic further, these additional resources will be useful.

1. Simulation (15-20 min)

This PhET simulation, “The Greenhouse Effect” by University of Colorado, shows the thermal effect of IR radiation in the presence of greenhouse gases. The tool can also be used to visualize the changes in vibrational modes of greenhouse gas molecules on exposure to IR light.

This tool can be accessed at:

https://phet.colorado.edu/en/simulation/greenhouse

2. Reading (~10 min)

This reading, “What are the properties of a Greenhouse Gas?” by American Chemical Society, describes the properties and compares the global warming potentials of several greenhouse gases based on their IR spectra.

This reading can be accessed at:

https://www.acs.org/content/acs/en/climatescience/greenhousegases/properties.html

3. Laboratory activity (~45 min)

The laboratory activity, “Building a spectrometer to explore Infrared Radiation and Greenhouse Gases” by American Chemical Society, helps students to build their own IR spectrometer and to compare the thermal potential of greenhouse gases on absorption of IR radiation.

This can be accessed at:

www.interchemnet.com/data/labs/F2016%20GH%20Gases/F2016%20GH%20Gases.pdf

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We have selected and analyzed the tools that align with the overall objective of our project and have provided the corresponding links. We do not claim ownership of or responsibility/liability for any of the listed tools.

1. **Video micro-lectures,** "Infrared spectroscopy (IR)", "Chemistry Vignettes: IR Spectroscopy" and "Chemistry Vignettes: Vibrational Modes":

   Royal Society of Chemistry

2. **Video micro-lecture**, "Greenhouse Gases"**:**

   Prof. David Archer, the University of Chicago

3. **Reading**, "Greenhouse Gases", Chapter 4, pg. 29-32, from the book "Global Warming: Understanding the Forecast"**:**

   Prof. David Archer, the University of Chicago

Additional Resources

1. **Simulation**, "The Greenhouse Effect":

   pHET Colorado

2. **Reading**, "Properties of greenhouse gases":

   American Chemical Society

3. **Laboratory Activity**, "Building a Spectrometer to Explore Infrared Radiation and Greenhouse Gases":

   American Chemical Society