Infrared light and greenhouse gases

An exploration of the climate science: how absorption of infrared light depends on the molecule and type of light

Goals:
1. To observe the infrared spectra of known gases using an infrared spectrometer.
2. To conduct an experiment comparing the thermal effect of infrared light on nitrogen and carbon dioxide gases.
3. To explore a molecules and light simulation to gain insight into what happens when different types of molecules are exposed to infrared light.
4. To explore the American Chemical Society Science Climate Toolkit: a resource for understanding and communicating climate science.
5. To communicate your observations and findings by constructing an analysis board and presenting your results to the lab class.

Introduction:

The American Chemical Society (ACS) has created The ACS Climate Science Toolkit (portal.acs.org/portal/PublicWebSite/climatescience/) to help understand and communicate the fundamental scientific principles involved in climate science:

“Global climate change, whether a result of natural variability or of human activity, is a vital issue for life on Earth and involves many processes and concepts related to chemistry. Engaging with this issue in deliberative discourse with colleagues and others requires understanding the fundamental science that determines Earth’s climate. This fundamental science is the core content of the ACS Climate Science Toolkit.”

In prior experiments, you used UV-vis absorption spectroscopy to look at the color of solutions, involving the absorption of light to promote an electron from a lower energy level to a higher energy level. In this lab, you will use another absorption technique, called infrared absorption spectroscopy, which involves the absorption of infrared light to promote a molecule from a lower vibrational energy level to a higher vibrational energy level. You will also conduct an experiment comparing the thermal effect of infrared light on nitrogen and carbon dioxide gases.
What is infrared light?

Infrared (IR) light is a type of electromagnetic radiation. It is associated with less energy than the wavelengths of electromagnetic radiation that we call visible light. IR light is invisible to the human eye, but we can feel it.

When you're standing near a woodstove, the warmth you sense is the result of you skin absorbing infrared light emitted from the stove. You may also be familiar way of "seeing" infrared light: thermal imaging. Thermographic cameras produce images by detecting infrared light emitted by surfaces. Whiter regions of the image of the cat to the right correspond with more infrared light being emitted from these areas and hotter surface temperatures.

What is infrared spectroscopy?

In the first experiment you will perform today, you will use infrared spectroscopy to observe how nitrogen (N_2) gas and carbon dioxide (CO_2) gas react to infrared light. IR spectroscopy is a technique used by chemists to determine the chemical makeup of a compound. The Fourier Transform Infrared (FTIR) Spectrometer exposes a chemical substance to light in the infrared range of the electromagnetic spectrum. A detector then measures the amount of light absorbed by the substance, and records the amount of light absorbed as a spectrum.

The infrared region of the electromagnetic spectrum is used because molecules vibrate when exposed to certain amounts of energy. If the energy associated with the infrared light from the instrument matches the energy of vibration of a molecule in the sample, the light will be absorbed. Molecules have a unique fingerprint of peaks shown by an FTIR spectrum because different molecules will absorb different wavelengths. The unique IR spectrum of water is shown below:
What does an infrared thermometer (sensor) measure?

In the second experiment you perform today, you will use an ordinary laboratory hotplate as a source of infrared light and a special type of thermometer that senses infrared light to observe differences in the amount of infrared radiation emitted by N₂ and CO₂ gas in polyethylene bags.

IR sensors allow you to make inferences about the amount of infrared light emitted from the surface of an object. Inside, the IR sensor contains an electronic element that converts the rate of incoming infrared photons to an electric current. The magnitude of the current is measured and converted into a temperature reading. The higher the amount of infrared light entering the gun, the higher the temperature reading on the sensor will be.

The distance the sensor is away from the target object effects the diameter of the bottom of the cone that the sensor can “see.” (See picture above). The larger the distance the sensor is from the object, the larger the diameter of the bottom of the cone. The IR sensor has a laser to help you see where it is aimed but it is not involved in the measurement.

Materials:

<table>
<thead>
<tr>
<th>Chemicals:</th>
<th>Supplies &amp; Equipment:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nitrogen gas (N₂)</td>
<td>Infrared Spectrometer</td>
</tr>
<tr>
<td>Carbon dioxide (CO₂)</td>
<td>Polyethylene bags and ties</td>
</tr>
<tr>
<td></td>
<td>Three regular sized ringstands</td>
</tr>
<tr>
<td></td>
<td>One extra tall ringstand</td>
</tr>
<tr>
<td></td>
<td>Four ringstand clamps</td>
</tr>
<tr>
<td></td>
<td>Hotplate</td>
</tr>
<tr>
<td></td>
<td>Two IR sensors</td>
</tr>
<tr>
<td></td>
<td>Posterboard and markers</td>
</tr>
</tbody>
</table>

Pre-Lab Assignment:

1. Please write a short summary of the experiments you will perform today.

2. Please prepare a safety table that lists the chemicals, their hazards, and the precautions you will take when handling them.
Overview:

The investigations you will engage in today are open-ended in the sense that you will be asked to come up with your own interpretation of what your observations suggest. For all of today's activities, we'd like you to work in a group of four (two pairs of partners). We would like you to discuss the questions marked with a "Q" as a group as you encounter them.

After performing the experiments, your task will be to come together and try and explain the physical phenomena you have observed and then use your explanation to make a prediction about a larger scale scenario. Because this is the last laboratory period of the semester, you will not be asked to individually write a laboratory report. Instead, as a group, you will present an argument based on your findings to the class at the end of the laboratory period.

![Experiment flowchart]

Part 1: Infrared spectroscopy: Obtaining infrared spectrums of nitrogen and carbon dioxide in a polyethylene bag

*Your laboratory instructor will guide you through this first experiment.*

1. Obtain bags of N₂ and CO₂ from the tanks with your instructor's assistance. Try to make sure that the volume and shape of each bag is more or less consistent. Secure each bag with a twist tie and label them above where they are tied off.

2. With your instructor's assistance, obtain the infrared spectrum of each gas. Because the instrument will contain air (primarily nitrogen and oxygen, as well as other trace gases) outside the sample bag, the instrument must be instructed to ignore the absorbance it records for these substances. Therefore, your instructor will help you “blank” the instrument so you are only recording absorbance due to the samples themselves. Polyethylene, the material the bag is made out of, also absorbs infrared light. Your instructor will help you identify which peak is due to polyethylene and can be ignored.

Q: What are the differences in the spectra of N₂ and CO₂?
Part 2. IR sensors: How CO\textsubscript{2} and N\textsubscript{2} interact with IR light

In this second experiment, your group will expose the bag of nitrogen gas to infrared light from a laboratory hotplate. One group will take readings from a infrared sensor aimed down at the top of the bag and the top of the hotplate and the other group will take readings from an infrared sensor aimed at the side of the bag across the hotplate. You will repeat this same process with the bag of carbon dioxide.

1. Plug in a hotplate and turn it to setting 2.

2. Find three regular size ring stands (they usually have black bases) and one extra-tall ringstand (the tall ones have white bases). Also, collect four ringstand clamps.

3. Place a clamp about 50 cm high on the tall ringstand. Clamp in one of the IR sensors so that it is pointing down at the hotplate and use the laser to make sure it is aimed at the center of the hotplate:

![Diagram of IR sensor and ringstand](image1)

4. Take a second ringstand and clamp the second IR sensor to it approximately 25 cm from the base of the stand so that it is pointing horizontally over the hotplate.

![Diagram of IR sensor and ringstand](image2)

5. The hotplate's temperature will slowly increase until it reaches a stable point. Take readings of the IR light emitted from the hotplate with the vertically pointing IR sensor and the horizontally pointing IR sensor periodically. Make sure that each IR sensor is pointed at a consistent spot and remains the same distance from the hotplate (this should not be a problem because you have it clamped in place).
5. Next, place clamps at approximately 25 cm from the base of the last two ringstands. These ringstands will hold the bag of gas with their clamps:

6. Arrange the ringstands so that you have one on each side of the hotplate:

7. Finally, blow up a polyethylene bag with air (use your breath), tie it off, and put it in the clamps over the hotplate so you can make sure the clamps and ringstands will be in the right positions for your sample bags. Adjust the clamps so that the IR sensor aimed sideways is about 10 cm away from the bag and aimed at the center of the bag. Adjust the IR sensor aimed downwards so that it is 10 cm from the bag and also aimed at the center of the bag. Then, make sure the bag fits in the clamps about 15 cm above the hotplate:
While you test each of your N₂ and CO₂ samples, you will want to keep the distances of the sensors as constant as possible (you want the only variable to be the type of gas in the bag). You can put tape down to mark the positions of the ringstands. **Discard the bag of air when you have the clamps and ring stands in the right position.**

8. Continue to monitor the temperature of the hotplate with the two sensors until they remain constant for at least five minutes. Once the temperature is stable, you can test your two samples.

9. Start with the nitrogen. To begin, first record the temperature of the hotplate without the nitrogen bag with both sensors. In your group of four, two people will be in charge of measuring temperature vs. time on the horizontally pointing IR sensor and the other two people will be in charge of measuring temperature vs. time on the vertically pointing IR sensor. Identify a way to keep time using a cell phone or the clock on the wall. When you're ready to keep time, set the nitrogen bag into the apparatus. Take a temperature reading with each sensor initially, and then every 60 seconds for 8 minutes. When you're finished, remove the bag and record the temperature of the hotplate.

10. Next, repeat this process with the carbon dioxide bag. Before you put the carbon dioxide bag in the clamps, check the temperature of the hotplate with the IR sensors. Make sure that the IR sensors are the same distances from this bag as they were for the nitrogen bag. Also, make sure when you clamp the CO₂ bag that it is the same distance from the hotplate as the nitrogen bag was. Record your time and temperature measurements. When you are finished, record the temperature of the hotplate without the bag.

*Once you have completed measurements for both bags, you can clean up and proceed to the breakout room for the next activities.*
Part 3. Inquiry into the phenomenon you have observed

Working in your group of four you will now try to make sense of your results and devise a molecular explanation of what is going on with the gases and the hotplate. First, we would like you to discuss the results. What differences did you observe? Then, you will be provided with two tools to devise an explanation of these results. The questions below are meant to be discussion questions to help guide your thinking as a group. You do not need to individually write answers to each one in your laboratory notebook. We’d rather have you talking and interacting with each other than writing by yourself! As a group you will be presenting your collective ideas to the rest of the class at the end of lab.

1. What are the results?

Nitrogen experiment:

   Q: What happened to the temperature over time as recorded by the IR sensor pointed at the side of the bag across the hotplate?

   Q: What happened to the temperature over time as recorded by the IR sensor pointed straight down at the bag and the hotplate?

Carbon dioxide experiment:

   Q: What happened to the temperature over time as recorded by the IR sensor pointed at the side of the bag across the hotplate?

   Q: What happened to the temperature over time as recorded by the IR sensor pointed straight down at the bag and the hotplate?

How do the two gases compare?

   Q: Was the hotplate emitting a steady amount of IR light the whole time?

   Q: What direction is infrared light leaving the hotplate in?

   Q: Measured from the side, does the carbon dioxide or nitrogen bag emit more infrared light? (Remember, a larger temperature registered means that more infrared light is being emitted).

   Q: Measured from the top, does carbon dioxide or nitrogen seem to emit more infrared light?

2. How can these results be explained?

   We would like you to try and provide an explanation of what is going on at the molecular level in these two experiments that results in the differences you observed. You will have two resources to use to help you devise your explanation: A computer simulation and the ACS Climate Science Toolkit.
**The PhET simulation “Molecules and Light”:**

Experiment with “Molecules and Light” while you are building your explanation as a group. PhET simulations are interactive animations featuring a variety of topics in chemistry, physics, and math that are difficult to visualize. The simulations are designed to provide insight into difficult topics, however, just like the analogies you worked with in earlier labs, keep in mind that they are imperfect representations of complex physical phenomena. The Molecules and Light simulation allows you to expose different kinds of molecules to different kinds of light and “observe” what happens.

To access the molecules and light PhET simulation use this link: [http://phet.colorado.edu/en/simulation/molecules-and-light](http://phet.colorado.edu/en/simulation/molecules-and-light)

Choose the “run now” option and experiment with the simulation to answer the following questions:

**Q:** What does the PhET simulation suggest about how carbon dioxide and nitrogen react differently to infrared radiation?

**Q:** Which of the other gases in the simulation behave the same way as carbon dioxide when exposed to infrared radiation? Which act like nitrogen?

**The ACS Climate Science Toolkit:**

As discussed earlier in the introduction, the ACS Climate Science Toolkit is a resource designed to provide insight into the chemistry of the Earth’s climate. In particular, it discusses how certain molecules interact differently with infrared light. Explore the Climate Science Toolkit pages to further develop your explanation.

You can access the ACS Climate Science Toolkit here: [portal.acs.org/portal/PublicWebSite/climatescience/](http://portal.acs.org/portal/PublicWebSite/climatescience/)

**Q:** What does the ACS Climate Toolkit page tell you about why some molecules interact with infrared radiation differently than other molecules?

**Q:** What are the properties of a greenhouse gas?

**Q:** What effects do greenhouse gases have on the atmosphere?
Part 4. A question to consider: thinking beyond the experiments

*Use the evidence you collected from infrared spectroscopy, your IR gun experiment, the PhET simulation, and the ACS climate toolkit to answer the question below as a group. Prepare an analysis board (paper and markers are provided) that summarizes your group's answer and the reasoning behind that answer to share with the class in a 5-minute presentation.*

How do you think increasing the concentration of CO$_2$ in the atmosphere would affect the amount of infrared radiation present in the atmosphere?

During the presentations you are encouraged to ask other groups questions!