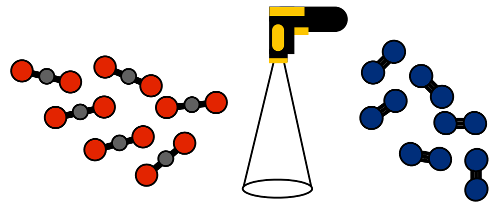
Building a Spectrometer to Explore Infrared Radiation and Greenhouse Gases

An exploration of climate science: the thermal effects of molecular absorption of infrared radiation



Goals:

1. To conduct an experiment comparing the thermal effect of infrared radiation (light) on nitrogen and carbon dioxide gases.
2. To explore a "Molecules and Light" simulation to gain insight into what happens when different types of molecules are exposed to infrared light.
3. To explore the American Chemical Society Climate Science Toolkit: a resource for understanding and communicating climate science.
4. To communicate your observations and findings by constructing a poster and presenting your results to the lab class.

Introduction

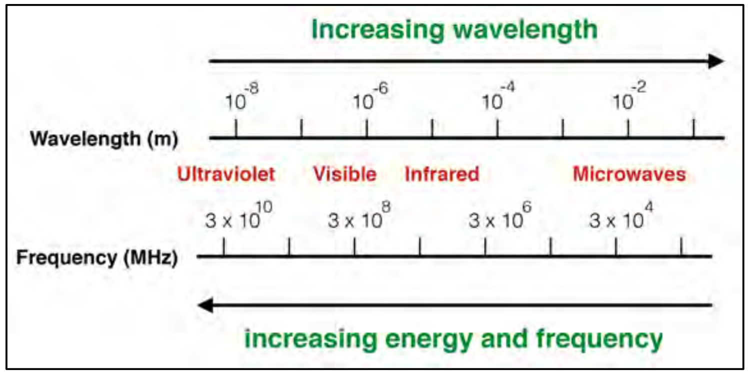
The American Chemical Society (ACS) has created The ACS Climate Science Toolkit (http://www.acs.org/content/acs/en/climatescience.html) to help you understand and communicate the fundamental scientific principles involved in climate science:

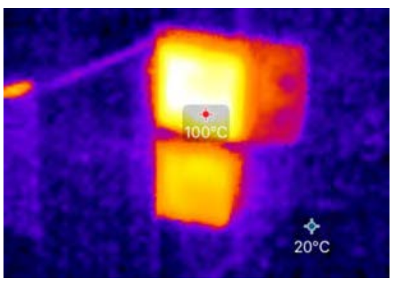
> *"Global climate change, whether a result of natural variability or of human activity, is a vital issue for life on Earth and involves many processes and concepts related to chemistry. Engaging with this issue in deliberative discourse with colleagues and others requires understanding the fundamental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

In this lab, you will use a technique called infrared spectroscopy, which involves the absorption of infrared radiation by a molecule to promote it from a lower vibrational energy level to a higher vibrational energy level. You will use this technique to explore how infrared radiation interacts with 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 electro-magnetic radiation that we call visible light. IR light is invisible to the human eye, but we can feel it. The Figure here shows a portion of the electromagnetic spectrum (EMS) illustrating the relationships between wavelength, frequency and energy.

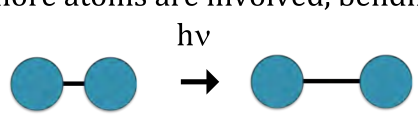




When you're standing near a woodstove, the warmth you sense is the result of your skin absorbing infrared light emitted from the stove. You may also be familiar with a way of "seeing" infrared light: thermal imaging. Thermographic cameras produce images by detecting infrared light emitted by surfaces.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

What is infrared absorption?

When light in the EMS is absorbed, light quanta matching the energy spacing requirements are accepted to increase the energy of the atom or molecule. For UV-vis, this involves the promotion of an electron from a lower energy to a higher energy orbital. For infrared, it involves vibrating bonds. When absorption of light occurs, it increases the vibrational state, which as shown in the cartoon below, can result in the bond length increasing. When infrared light is absorbed, various changes in the vibrational states can occur, including bond lengthening, and, if three or more atoms are involved, bending.

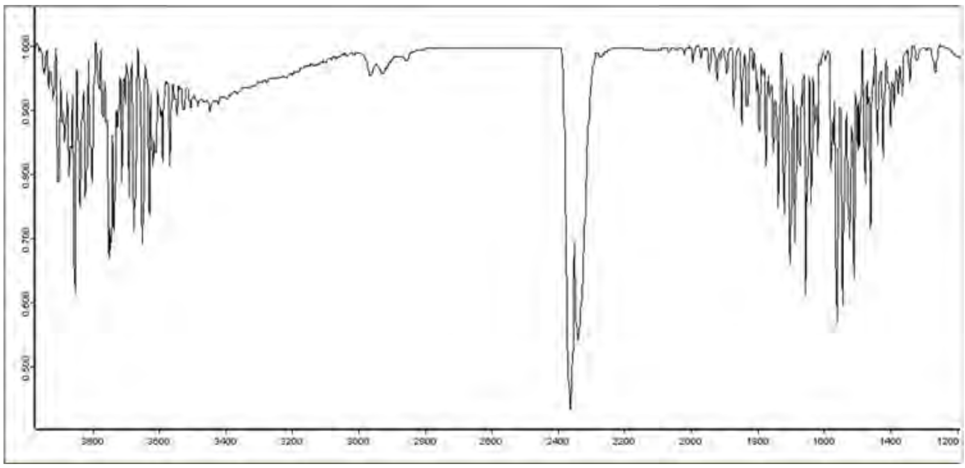


In today's experiment you will use an infrared thermometer to observe how plastic bags filled with nitrogen (N_2) gas and carbon dioxide (CO_2) gas interact with infrared light. You will do this by building an infrared spectrometer, which has an IR source, sample (bag filled with gas), and detector all in a straight line as shown below:

Infrared heat source → sample (bag filled with gas) → infrared detector

Infrared spectrometers

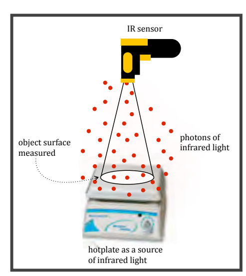
The IR spectrometer you will build and use today is a simplified version of an instrument that chemists use in research labs called a Fourier Transform Infrared (FTIR) Spectrometer. An FTIR spectrometer is used to record the amount of infrared radiation transmitted through a sample as a function of the energy of the infrared radiation (see Figure below). There are several online databases that provide infrared spectra of many different molecules; see for example the National Institutes of Standards (NIST) database at http://webbook.nist.gov/chemistry/.



Infrared spectrum of room air. Y axis: transmittance vs. X axis: wavenumber (cm^{-1})

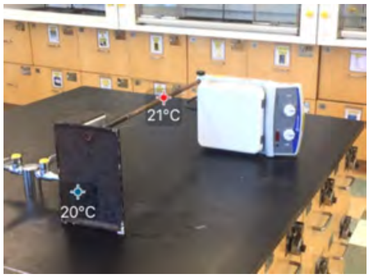
What does an infrared thermometer (sensor) measure?

IR sensors allow you to make inferences about the amount of infrared light emitted from the surface of an object. For example, see the images of the hot plates shown below. 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 sensor, the higher the temperature reading on the sensor will be. Please note that the accuracy of the sensor may not be very good. However, we can experimentally adjust for this by taking relative measurements of the temperature. We can compare *the changes* in temperature we get when each bag filled with a different gas is placed in the sample holder.



The distance between the sensor and the target object affects the diameter of the bottom of the cone that the sensor can "see." (See picture at the right). 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.

A.



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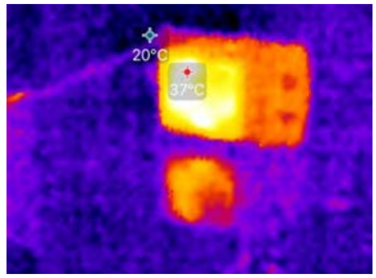

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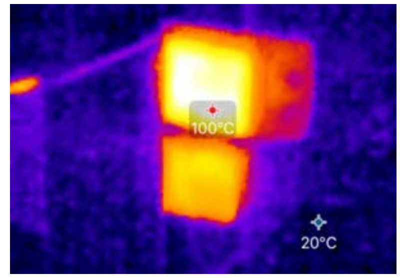


Images of hot plate. A. Photograph before turning on hot plate. B. Thermal image just after turning on hot plate. C. Thermal image a few minutes later (Seek thermal camera).

Hazards

- Do not touch the hot surface of the hot plate.
- Placing the hot plate on its side may create a burn or fire hazard. Precautions need to be taken to ensure that the surface it is placed on is nonflammable and an appropriate notice is posted to warn students of this potential hazard.
- Do NOT test methane or any other flammable gases.
- The infrared thermometer uses a laser for alignment purposes. Please do not point the laser at someone or look into the beam of the laser.

Note again: the laser light is useful in aligning the path of our spectrometer but is not important to the measurement of IR radiation.

Materials:

Chemicals:	**Supplies & Equipment:**
Nitrogen gas (N_2) Carbon dioxide (CO_2) Optional: Deionized water Sodium chloride (NaCl)	Polyethylene bags and twist-ties. Ring stands & clamps Hot plate IR thermometer Plastic test tube rack (sample holder) Poster board and markers

Pre-Lab Assignment:

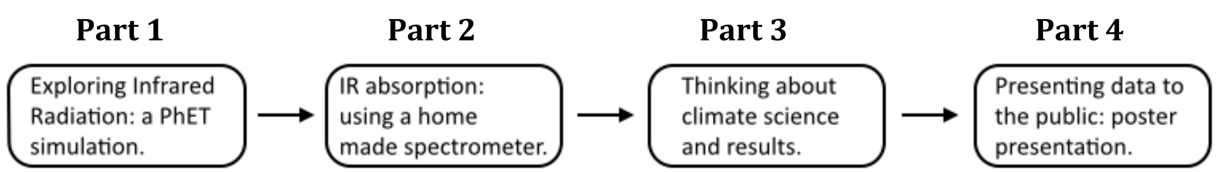
1. Write a short summary of the experiments you will perform today.

2. Prepare a safety table that lists the chemicals, any hazards, and the precautions you will take when handling the chemicals and equipment.

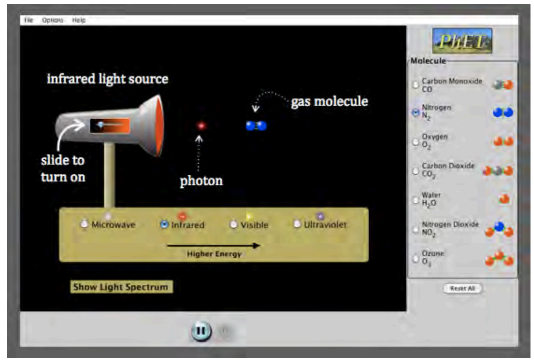
Overview

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, you will work in a group of three to four students (two pairs of partners). Discuss any questions marked with a "Q" as a group, as you encounter them.

After performing the experiments, your task will be to come together to explain the physical phenomena you have observed and then use your explanation to make a prediction about a larger scale scenario. Each group will construct a poster and then present your findings to other groups in a 5-min presentation at the end of the laboratory period. Your lab score will be based on the prelab assignment (10 pts), the poster (70 pts), and the presentation (20 pts). In addition, there is extra credit available for this lab (up to 20 pts). All extra credit must to be submitted within two days of presenting the poster.



Part 1: The PhET simulation "Molecules and Light"



Screenshot for the PhET simulation: Molecules and Light, used with permission from PhET Interactive Simulations, University of Colorado Boulder, http://phet.colorado.edu

Experiment with "Molecules and Light". 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
Choose the "run now" option and experiment with the simulation to answer the following questions:

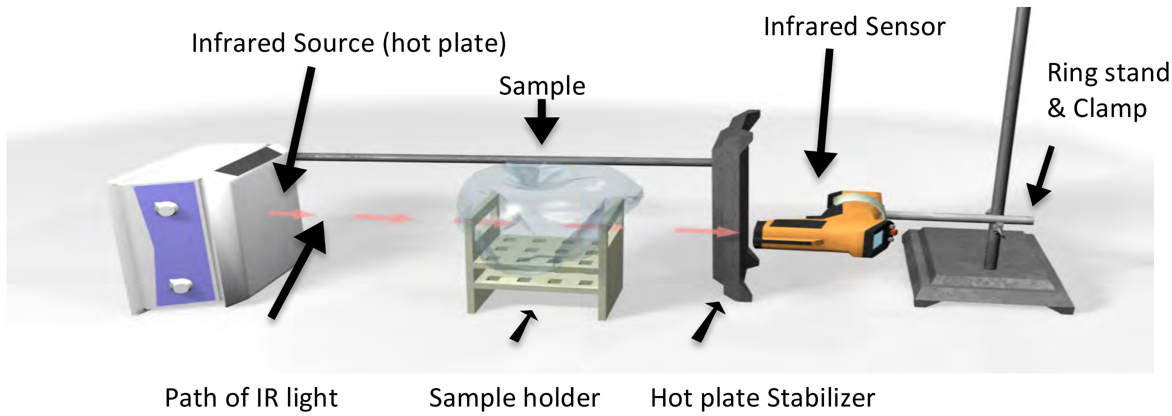
Q: What does the PhET simulation suggest about how carbon dioxide and nitrogen react differently to infrared light?

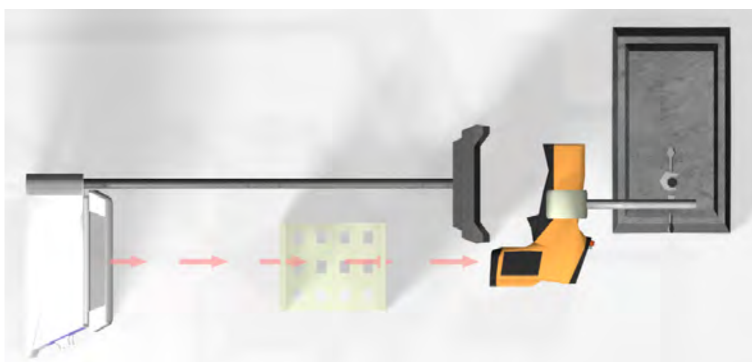
Q: Which of the other gases in the simulation behave the same way as carbon dioxide when exposed to infrared light? Which gases act like nitrogen?

Part 2: IR absorption of various substances: using a home built spectrometer.

Building an IR spectrometer

Your lab instructor can help your group assemble the spectrometer below. An important feature is that there must be a clear path for the IR light to go through the holes in the sample holder to the infrared detector. The hot plate stabilizer should not block the IR light to the detector.





Placing the hot plate on its side may create a burn or fire hazard. Precautions need to be taken to ensure that the surface it is placed on is nonflammable. Keep plastic bags away from the hot plate surface. Make sure the hot plate stabilizer does not block the beam path and that there is a clear path from the infrared source through the sample holder and to the sensor.

Your finished setup should look like this.

Making Measurements

1. Obtain bags of N_2 and CO_2 from the tanks with your instructor's assistance. Do not overfill bags, so that you can press them into the shape of the sample holder (as shown in the pictures below).

A.

B.

Plastic Bag Figure. Partially filled plastic bag: (A.) in the sample holder, and (B.) in the sample holder - but pressing gently down to mold the bag into the shape of the sample holder.

2. To make measurements, one student holds down the IR thermometer trigger for 10-15 seconds to stabilize the detector before measurements can be made. Another student can place the sample in the sample compartment, gently holding down the bag, while another student can record the temperature of a blank measurement (nothing in the compartment) or a sample in the compartment.

The experiments:

Design a set of experiments to explore the following question:

Scientific Question #1: Comparing the absorption of infrared light in the presence and absence of each different sample of gas, are there any significant differences that can be observed experimentally?

Using the ***Designing Experiments*** worksheet to summarize this process, your group should describe a lab procedure to explore the scientific question #1. A copy of this worksheet will be fixed to the poster that your group will construct in part four. Before collecting data, you need to explain your procedure to your lab TA.

Note that the plastic bag absorbs some IR radiation, but since we are comparing the absorption of IR light in the presence and absence of each sample, the influence of the bag is subtracted out of the measurements.

Extra Credit - Extra Challenge: IR spectroscopy (10 pts)

Your group can extend its data set by investigating other substances. The presence of substance such as water or salt can influence IR absorption in the atmosphere. Your group can design experiments to extend your original study by including the influence of water or salt in the presence of nitrogen and or carbon dioxide. Water may be introduced into a bag, and the bag moved around to promote the formation of water vapor. Salt can be crushed, to increase its surface area, and then introduced into a bag. Your group can also propose the investigation of other substances. In order to receive extra credit, you should describe the results on your poster as well as in the summary submitted. Caution: Do NOT test methane or any other flammable gases.

Designing Experiments Worksheet

Please use this sheet to summarize your lab group's experiment and findings. ***Before going into lab, have your lab instructor check and initial it.***

Names:	Experiment #:
Signatures:	Section:

Please describe your proposed experiment. *(Check in with your lab instructor before performing experiments)* Instructor's initials:________	(attach extra pages if needed)
Describe the data you collected:	(attach extra pages if needed)
What claims can you make?	

Part 3. Thinking about climate science and results.

A. The ACS Climate Science Toolkit: 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. We'd like your group to look at this website to answer the questions below. The answers should be written in your lab notebook.

Climate Science Toolkit Logo used with permission from the American Chemical Society.

You can access the ACS Climate Science Toolkit here:

http://www.acs.org/content/acs/en/climatescience.html

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

Q: What are the properties of a greenhouse gas?

Q: What effects do greenhouse gases have on the atmosphere?

B. Inquiry into your experimental results: *Each group should discuss your results and devise a molecular explanation for what is going on with the gases and the hot plate. Did you observe any differences between gases? The PhET simulation and the ACS Climate Science toolkit are resources to help you think about your explanation. The questions below are meant 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 in a poster format to the rest of the class at the end of lab.*

1. What were your results?

2. How can the data be presented to help understand the results?

3. Were differences seen that are statistically significant?

4. How did your group's procedures help or hinder good data from being collected?

5. What molecular interpretation can be invoked to help explain the data?

Part 4. Presenting data to the public: poster presentation

Use the evidence you collected from your IR sensor experiment, the PhET simulation, and the ACS climate science toolkit to answer scientific question #2 below as a group. Prepare a poster (poster board 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.

Scientific Question #2: How do you think increasing the concentration of CO_2 in the atmosphere would influence the amount of infrared light absorbed and the energy present in the atmosphere?

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

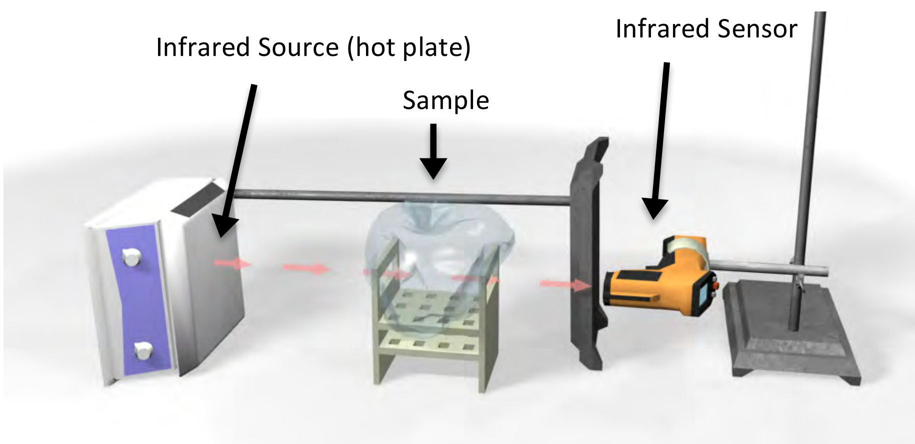
C. In order to receive credit for the poster presentation, everyone in each group is required to submit the Designing Experiments Worksheet to your TA before your presentation.

Your lab score will be based on the prelab assignment (10 pts), the poster (70 pts), and the presentation (20 pts). In addition, there is extra credit available for this lab (up to 20 pts). All extra credit must be submitted within two days of presenting the poster.

Note: there are two types of extra credit possibilities for this experiment:
a. Extra Credit - Extra Challenge (see page 8): up to 10 pts
b. Postlab question (see below): up to 10 points.

To submit extra credit, you should upload a word or pdf file to ICN exactly as you would a lab report. For the Extra Credit - Extra Challenge, the file should contain a summary of what additional experiments you carried out (see pg 8). For the postlab extra credit, the file should include your answers to the post lab question (shown below).

Post lab question (extra credit): Considering the home-built spectrometer below that you worked with in lab, do you think there is an analogy to be made between how the home built IR spectrometer works (IR source => Gas Sample => Detector) and the interactions of radiation in our atmosphere with greenhouse gases? Please explain. In your explanation, you should describe the similarities and differences between a spectrometer and atmospheric interactions.



Rubric for the Poster

Title and Team Member Names **(5 pts)**	**<u>Introduction:</u>** Contains title, Team member names, and brief statement about the poster
ACS Climate Science Toolkit (5 pts)	**<u>ACS Climate Science Toolkit</u>** Explain the information you found on the ACS Climate Science Toolkit
PhET Simulation (5 pts)	**<u>PhET Simulation</u>** Explain the "Molecules and Light" simulation
Designing Experiments Worksheet (10 pts)	**<u>Designing Experiments Worksheet</u>** Explain the procedure used in the experiments you designed.
Results: Scientific data that supports the claim. **(10 pts total)**	**<u>Designing Experiments Worksheet (attach to poster)</u>** **<u>Results</u>** Summarize your experimental data in a table or figure.
Reasoning: Scientific explanations that use evidence and appropriate chemistry concepts to construct claims. **(20 pts total)**	**<u>Reasoning:</u>** Present an analysis of your results[§] [§]You may be able to use the PhET simulation in explaining your data.
Claim(s): Statement(s), derived from evidence, using scientific reasoning. **(15 pts total)**	**<u>Summary of claims:</u>** What claims can you construct? Present your evaluation of the scientific question #2: "How do you think increasing the concentration of CO_2 in the atmosphere would influence the amount of infrared light absorbed and the energy present in the atmosphere?"