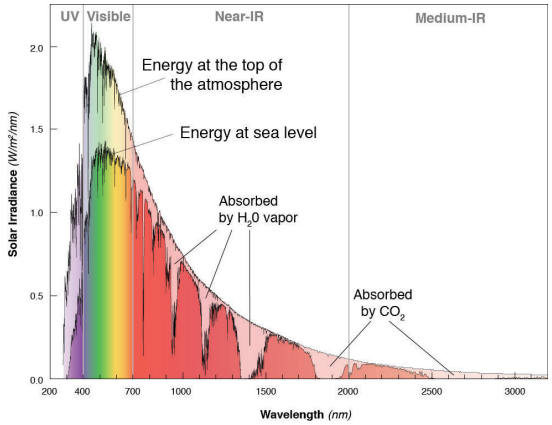
NYC STEM Summer Institute: Climate To Go!
Infrared detection of carbon dioxide



Standards
NGSS PS3A: Definitions of Energy
NGSS PS4B: Electromagnetic Radiation
NGSS ESS2D: Weather and Climate
NGSS ESS3D: Global Climate Change

Equipment
IR thermometer
Mug warmer/hot plate
CO_2 meter
Juice bottle "cuvette"
Small water dish (2-4oz)
Sodium bicarbonate tablets (Alka-Seltzer)
Frame – wood or LEGO – for assembling experiment
Clock/timer/smartphone

Why?
Atmospheric gasses are invisible, thus difficult to study, yet they play a critical role in maintaining the health and viability of human and natural communities. The interactions between energy and atmospheric gasses keep our planet habitable and maintain long-term global temperatures. Carbon dioxide – although a trace gas in the atmosphere – is an important ***greenhouse gas*** because it absorbs IR energy emitted by the Earth.

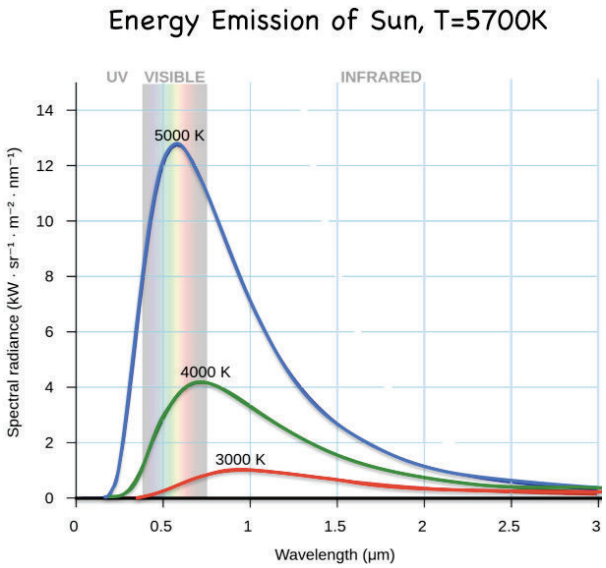
What?
In this activity we will measure the absorption of infrared (IR) energy by carbon dioxide gas. Two pieces of instrumentation will allow us to study something we cannot see; (1) an inexpensive IR thermometer and (2) a CO_2 meter. The learning goals for this experiment are:

- Build an apparatus to detect carbon dioxide gas
- Describe the importance of energy absorbance
- Explain the response of the IR detector

How?
We will use a mug warmer to shine a beam of IR energy through a plastic cuvette to an IR detector – the IR "thermometer." We will introduce CO_2 gas into the cuvette and use the CO_2 meter and IR detector to monitor the changes that take place through the course of the experiment. This experiment is designed to use inexpensive and home-made components. In Part 1 we will build and assemble the pieces.

About IR Detectors

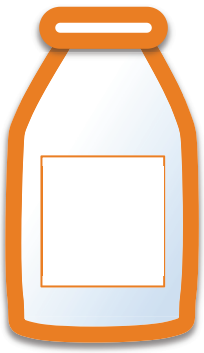
All objects emit energy. The kind of energy emitted (its wavelength or frequency) is a function of the surface temperature of the object. Very hot objects (like stars) emit energy across a range of wavelengths that spans from very short x-rays to very long radio waves, but the peak of the emission spectrum is in the visible range (*Figure 1:* note that the peak of the emission spectrum moves to longer wavelengths at lower temperatures). For a cooler object like a human body, the peak of the emission spectrum is in the infrared range. An instrument that can measure wavelength can convert that measurement to temperature. We make use of IR detectors to calculate temperature routinely – a standard "ear thermometer" does exactly that. A child with a fever emits energy at a shorter wavelength than one without.



In this experiment we will use an IR detector that automatically calculates temperature. For our purpose this handy feature adds a bit of complication – we aren't really interested in temperature at all – we want to know if the energy is reaching the detector or if it gets absorbed in between the source and the detector. Because our IR source has a constant temperature, a drop in the reported value on our IR detector is a measure of energy absorbance.

Part 1 - Build the Experimental Components

- Make a plastic juice bottle cuvette. The cuvette will hold the sample of CO_2 gas. The cuvette should have flat, parallel sides constructed from an IR-transparent material. The photos in this handout show a 32-oz plastic lemonade bottle with two square windows cut from the sides and covered with food-grade plastic wrap. The square windows, when covered with the plastic wrap, create the two flat parallel sides of the cuvette. Other containers could be used (a milk carton would probably work almost as well). Plastic wrap is a great IR-transparent window. We will also need to cut a hole – square or circular – in the bottom of the cuvette so that we can place it over a small water dish.



- Construct a frame to hold the experiment. The frame will hold the mug warmer in a vertical position, and should elevate the IR thermometer so that it targets the surface of the mug warmer. A frame will also allow the students to reproduce their experiment using nearly-identical dimensions, thus reducing a source of error and uncertainty. The frame shown in the photo here is made from LEGO bricks. A platform holds the IR thermometer (sideways) and orthogonal to the windows in the cuvette. The brace for the mug warmer is 14cm behind the cuvette.

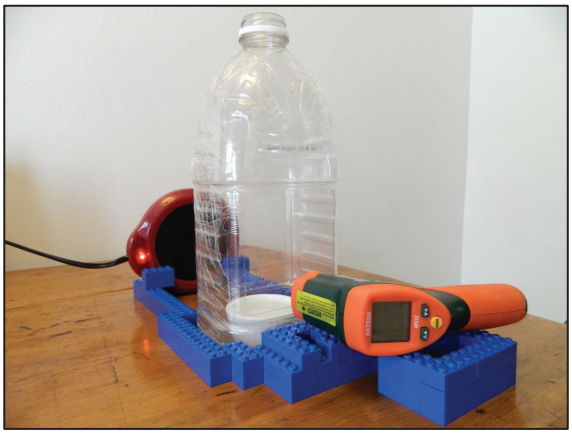


Figure 2: Experimental setup.

CO_2 Gas Source

The source of CO_2 gas for this experiment will be sodium bicarbonate antacid tablets dissolved in water. The sodium bicarbonate ($NaHCO_3$) dissociates to form carbonic acid (H_2CO_3) which in turn dissociates to release CO_2 gas:

$$NaHCO_3 + H_2O \Rightarrow Na^+ + H_2CO_3 + OH^-$$
$$H_2CO_3 \Rightarrow H_2O + CO_2$$

Part 2 – Assemble & Prepare the Experimental Apparatus

This experiment is designed to detect changes that occur when CO_2 gas is introduced into the sample cuvette. Thus the equipment should be set up and allowed to stabilize prior to running the experiment. In particular, a typical mug warmer needs about 30 minutes to achieve its stable temperature, and some types of CO_2 meters also benefit from being turned on and left running for 10 minutes or so prior to recording data. The IR detector needs no special prep, although make sure it is set to read in the units you will use (C/F).

- Place the mug warmer in a vertical position in the frame and turn it on.
- Fill the small water dish with water and set it in the frame; place the cuvette over the dish.
- Position the CO_2 meter in/on the bottle opening on the top of the cuvette. Turn the CO_2 meter on. If you will record the CO_2 data with a computer connect it to the meter and launch the logging software.
- Position the IR detector on its platform. Use a rubber band around the detector and platform to hold it in place.
- Get ready to keep track of run time of the experiment, using either a watch, smartphone, or the logging software on the computer.

- Data for time, IR, and CO_2 can be recorded by hand, entered into a spreadsheet, or logged via a computer interface (the IR detectors described here do not have an automatic logging option).

PART 3 - RUN THE EXPERIMENT

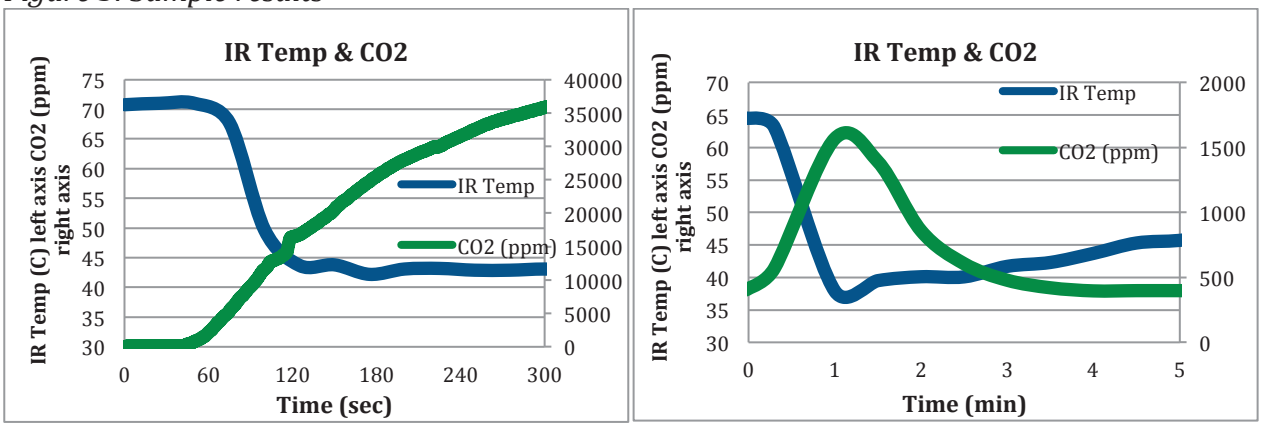
- Run the experiment in "blank" mode – without adding the sodium bicarbonate tablets – for one minute. Record data at a convenient time interval (every 15 or 30 seconds is good).
- At one minute, lift the cuvette enough to add two sodium bicarbonate tablets to the water dish. Immediately replace the cuvette.
- Continue recording data for 8 additional minutes.
- Graph the results.

Time (min)	IR (C)	CO2 (ppm)
0		
0.5		
1		

Add two $NaHCO_3$ tablets.

1.5		
2		
2.5		
3		
3.5		
4		
4.5		
5		

Figure 3: Sample results



Experimental results using two different CO_2 meters. Left, Vernier GoDirect CO_2 Gas probe. Right, TIM12 Desktop CO_2 Logger. Both experiments are run for 5 minutes. The Vernier probe effectively seals the cuvette thus CO_2 levels do not decrease during the experiment. The TIM12

allows CO_2 in the cuvette to mix with outside air. Both experiments show strong absorption of IR energy when CO_2 is added to the cuvette.

DISCUSSION: WHAT IS HAPPENING HERE?

The vertical surface of the mug warmer shines a "beam" of IR energy through the cuvette to the lens of the IR detector which records its intensity. The first data points prior to introducing CO_2 gas into the experiment show the behavior of the IR detector in its baseline configuration when it is monitoring the IR energy passing through the air in the cuvette. The sodium bicarbonate tablets react with water to exsolve CO_2 gas into the atmosphere of the cuvette. When CO_2 is added the intensity measured by the IR detector decreases. Like a cloud passing over the sun, the CO_2 gas is interfering with the beam of IR light.

Carbon dioxide is a very strong absorber of infrared energy. The CO_2 molecules absorb energy at specific wavelengths, which cause the molecules to vibrate at a higher amplitude than normal. For example, infrared energy with a wavelength of 15 micrometers (which the 400K mug warmer emits) is absorbed by the CO_2. This absorption will cause the linear CO_2 molecule to bend (or "flap"). In the cuvette we observe that absorption as the decreased intensity measured by the IR detector. In Earth's atmosphere the increased vibrational energy increases collisions with other molecules, thus raising the temperature of the atmosphere. The CO_2 molecule eventually re-emits the absorbed energy, which can continue to be re-absorbed and re-emitted until it finally escapes to space. With more CO_2 in the atmosphere it is more difficult for IR energy – emitted by the Earth – to escape directly to space, therefore we see increased temperatures in the atmosphere.

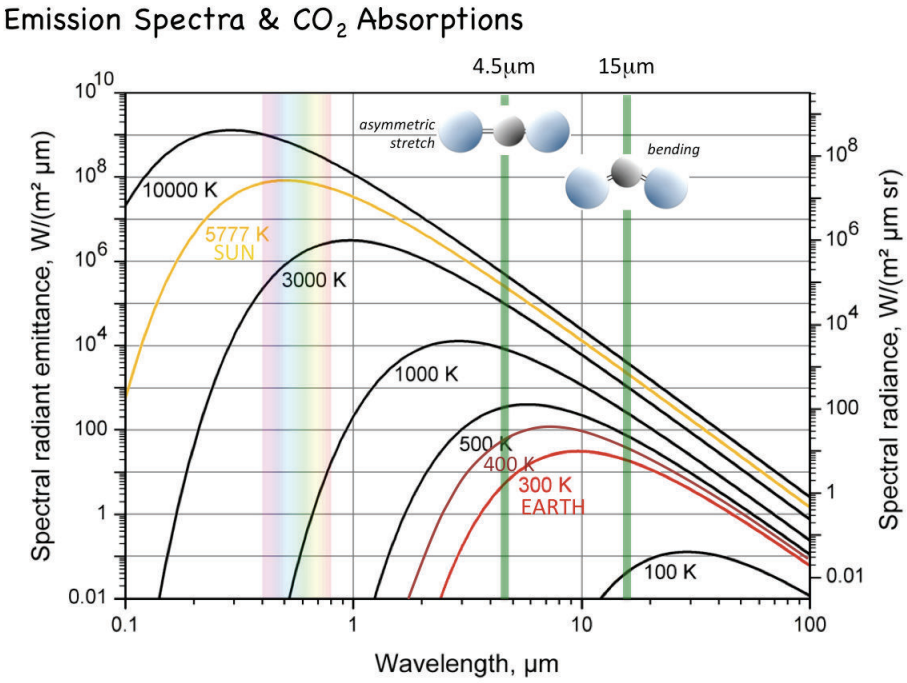


Figure 4: Emission spectra for different temperatures. Earth = 300K, mug warmer = 400K. Energy from both the Earth and the mug warmer cause a bending vibration in CO_2 molecules.

References and Resources

- TED Ed video on molecular vibration (including CO_2): https://www.youtube.com/watch?v=b0IbXG0hnOk
- Black Body Radiation entry on Wikipedia: https://en.wikipedia.org/wiki/Black-body_radiation

Equipment

- Vernier GoDirect CO2 Gas probe: https://www.vernier.com/products/sensors/co2-sensors/gdx-co2/
- TIM12 Desktop CO2 logger: https://www.co2meter.com/collections/desktop/products/tim12-desktop-co2-rh-t-monitor-data-logger
- Extech 14252 Infrared thermometer: http://www.extech.com/display/?id=14252
- Etekcity Lasergrip 800 Infrared thermometer: https://www.etekcity.com/product/100040

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