Environmental Science Institute
THE UNIVERSITY OF TEXAS AT AUSTIN

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(512) 471-5847
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Infrared Investigations: GHG

Lesson plan for grades 9-12
Length of lesson: 1 Class period, 75 minutes
Adapted by: Jesús Aguilar-Landaverde, Environmental Science Institute, October 2012

Authored by: U.S. Department of the Interior, U.S. Geological Survey, March 2011

SOURCES AND RESOURCES:

- Elmhurst College: Greenhouse Gases and Infrared Radiation
  http://www.elmhurst.edu/~chm/vchembook/globalwarmA5.html
- Suffolk Community College - Global Climate Change: The Smoking Guns for Humans
  http://www2.sunysuffolk.edu/mandias/global_warming/smoking_gun_humans_climate_change.html
- Radiative Forcing Source:
  - Forster, P., V. Ramaswamy, P. Artaxo, T. Berntsen, R. Betts, D.W. Fahey, J. Haywood, J. Lean, D.C. Lowe, G. Myhre, J. Nganga, R. Prinn, G. Raga, M. Schulz, and R. Van Dorland, 2007: Changes in atmospheric constituents and in radiative forcing. In: *Climate Change 2007: The Physical Basis*. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor, and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, UK, and New York
    - http://www.ipcc.ch/pdf/assessment-report/ar4/wg1/ar4-wg1-chapter2.pdf
- Texas Education Agency – Science, contains links to safety standards
  http://www.tea.state.tx.us/index2.aspx?id=5483
- Texas Instruments (TI) – Getting Started with the CBL 2 ™ system
  http://education.ti.com/guidebooks/datacollection/cbl2/cbl2-eng.pdf
- University Corporation for Amospheric Research (UCAR): Greenhouse Effect Background
  http://www.ucar.edu/learn/1_3_1.htm
- University of California San Diego: Radiation Balance
  http://earthguide.ucsd.edu/virtualmuseum/climatechange1/02_3.shtml
- Vernier LabQuest® Temperature Probe Manual
  http://www2.vernier.com/booklets/tmp-bta.pdf
- YouTube: User submitted video on using the Vernier LabQuest® temperature probe
  http://www.youtube.com/watch?v=Er5o99hKq3Y
- "Black Swans & the U.S. Future: Building Sustainable & Resilient Societies" by Dr. David W. Orr, Professor of Environmental Studies and Politics, Oberlin College. *Hot Science – Cool Talks*, Friday, September 14, 2012. The University of Texas at Austin. Webpage Containing Presentation, and Lecture

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Webcast: http://www.esi.utexas.edu/k-12-a-the-community/hot-science-cool-talks/black-swans-a-the-us-future-creating-sustainable-a-resilient-societies

POTENTIAL CONCEPTS & TEKS ADDRESSED THROUGH THIS LESSON:

§112.37.c. Environmental Systems, Grade 9-12: 1, 2 (F,G,H,I), 6C, 8 (B,E), 9D

§112.36.c. Earth and Space Sciences, Grade 9-12: 13D, 14B

PERFORMANCE OBJECTIVES (in order of increasing difficulty to permit tailoring to various age groups):

Students will be able to:

- Compare and contrast the thermal properties of methane, carbon dioxide, and saturated air to normal, non-saturated air.
- Provide a qualitative description of the greenhouse effect.
- Identify that greenhouse gases are effective at absorbing infrared radiation.
- Explain the concept of radiative forcing and greenhouse gas concentrations to this quantity.
- Relate positive radiative forcing with increasing global temperatures.

MATERIALS:

- Clear plastic water bottles with hole drilled into cap (recommend one bottle for every 3 students). The bottles should all be the same type, have clear plastic sides (remove any labels), and all be approximately 20 ounces in size.
- One Vernier LabQuest® interface
- One Vernier LabQuest® Temperature Probe (distributed separately)
- Vinegar
- Baking Powder
- Methane Gas (from laboratory gas jet)
- Light source (clamp lamp or goose neck) and bulb (standard incandescent or directed spot; one setup for each bottle).
- One data sheet and one instructions sheet per group (both attached separately).
- Data Table
- Graphing Worksheet
- Instructions Sheet
- Evaluation Worksheet

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CONCEPTS:

Radiative forcing is usually quantified as the 'rate of energy change per unit area of the globe as measured at the top of the atmosphere', and is expressed in units of 'Watts per square metre' (see Figure 5). When radiative forcing from a factor or group of factors is evaluated *as positive*, the energy of the Earth-atmosphere system will ultimately increase, leading to a **warming** of the system. In contrast, for a *negative* radiative forcing, the energy will ultimately decrease, leading to a cooling of the system. Important challenges for climate scientists are to identify all the factors that affect climate and the mechanisms by which they exert a forcing, to quantify the radiative forcing of each factor and to evaluate the total radiative forcing from the group of factors. (IPCC, 2007)

Human activities contribute to climate change by causing changes in Earth's atmosphere in the amounts of greenhouse gases. The **largest known contribution comes from the burning of fossil fuels**, which releases carbon dioxide gas to the atmosphere. Greenhouse gases (and aerosols) affect climate by altering incoming solar radiation and out-going **infrared (thermal)** radiation that are part of **Earth's energy balance**. Changing the atmospheric abundance or properties of these gases and particles can lead to a warming or cooling of the climate system. Since the start of the industrial era (about 1750), the overall effect of human activities on climate has been a warming influence. The human impact on climate during this era greatly exceeds that due to known changes in natural processes, such as solar changes and volcanic eruptions. (IPCC, 2007)

Carbon dioxide is a greenhouse gas and has increased from fossil fuel use in transportation, building heating and cooling and the manufacture of cement and other goods. Deforestation releases CO2 and reduces its uptake by plants. Carbon dioxide is also released in natural processes such as the decay of plant matter. (IPCC, 2007)

Methane is also a greenhouse gas and has increased as a result of human activities related to agriculture, natural gas distribution and landfills. Methane is also released from natural processes that occur, for example, in wetlands. Methane concentrations are not currently increasing in the atmosphere because growth rates decreased over the last two decades. (IPCC, 2007)

Water vapor is the most abundant and important greenhouse gas in the atmosphere. However, human activities have only a small direct influence on the amount of atmospheric water vapor. Indirectly, humans have the potential to affect water vapor substantially by changing climate. For example, a warmer atmosphere contains more water vapor. Human activities also influence water

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vapor through CH4 emissions, because CH4 undergoes chemical destruction in the stratosphere, producing a small amount of water vapor. (IPCC, 2007)

BACKGROUND:

In his September 14, 2012 *Hot Science – Cool Talks* outreach lecture (see Sources and Resources) Dr. David Orr discussed "Greenhouse Gasses (GHGs) as primary factors contributing to climate de-stabilization and change. In this lesson, the students will work with laboratory technology to empirically explore the properties of greenhouse gasses such as methane, water vapor, and carbon dioxide as they relate to air. These gases are among the long-lasting greenhouse gases whose increasing concentrations in the earth's atmosphere contribute significantly to a net positive radiative forcing, thereby contributing to a net increase in the earth's mean surface temperature. The students will collect data in the first part of this lesson, exposing samples of gas to the strong infrared radiation of incandescent light bulbs. A class comparison of this time series data should reveal how much more effective these gases are at absorbing and retaining heat. From this follows discussion on how these physical and chemical properties are directly relevant to the Earth's balance of energy in light of increasing global greenhouse gas emissions.

PREPARATION:

It is recommended that the instructor prepare the necessary incandescent bulb with the appropriate stands or clamps prior to the lesson for each group.

ENGAGE:

What better way to introduce greenhouse gas radiative forcing than with the most extreme case in the solar system? Below is an artist's conception of the surface of the planet Venus.

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Artist's conception of the surface of venus. Image credit: ESA/C. Carreau

Ask:
A fun lead in might be to ask the students to speculate where such a landscape might be.
Could it be some place on Earth?
Something out of dark fiction?
Why might the colors be the way they are?
Is this anything at all like Earth?
Or, alternatively, the instructor could open by asking: "What is the hottest planet in the solar system? Why?"

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Note to teachers:
Many students may answer Mercury, and the reason for Venus being much hotter is at the heart of this lesson. Although it may be acknowledged that the thick atmosphere of Venus is the main cause, there need not be any detailed discussion of the mechanism at work yet in this brief (maximum 5 minutes) introduction. Once the topic of Venus is established, it can suffice then to move on to begin to answer the question of *why exactly* Venus is as hot as it is through *experiment in the lab.* Another transition might be to announce that the students will be *both* climate scientists *and* planetary scientists in one day.

EXPLORE:
The procedure for this section will be very closely following the original activity procedure from the USGS; this lesson features the LabQuest® educational equipment. Instructions for each group are in a separate attached file, and it is written to the students as if they were practicing scientists. This activity is written here for a measurement time of twenty minutes, but it readily modifiable to more or less. Given the dependence on the heating from radiation of the incandescent source, it should be noted that too short a time (less than approximately ten minutes) might not produce the desired results.

SPECIAL SAMPLE PREPARATION (USGS):

For the bottle with air: Just tighten the cap.

For the bottle with saturated air: Place a piece of saturated sponge in the bottom of the bottle. Make certain it is large enough to cover at least half of the bottom of the bottle.

For the bottle with carbon dioxide and for pouring the gas into the bottle:

Carbon dioxide can be easily made with baking soda and vinegar. Vinegar (acetic acid) CH_3COOH, and baking soda (sodium bicarbonate) $NaHCO_3$ produces an acid-base reaction when they come in contact with one another. The fizzing and bubbling indicates that a gas (CO_2) is being produced. Chemically, the reaction is:

$CH_3COOH + NaHCO_3 \rightarrow CH_3COONa + H_2CO_3$

The H_2CO_3 (carbonic acid) quickly turns into carbon dioxide and water.

$H_2CO_3 \rightarrow H_2O + CO_2$

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(The CO2 is what you see in the foaming and bubbling in this reaction.)

Pour 30 ml (about 1 ounce) of vinegar into a plastic cup or beaker. Spoon in ½ tsp of baking powder. Allow the reaction to bubble and fizz without disturbing it. When the fizzing is over, carefully pour the CO2 into the bottle. [Adding more vinegar and baking soda will just make the reaction bubble excessively, and the CO2 will tend to bubble over the beaker and you won't be able to get it into the bottle.] BE CERTAIN NOT TO POUR ANY LIQUID INTO THE BOTTLE! Repeat this process two more times. Put the cap on the bottle.

Note: CO2 gas is denser than air. It will stay in the beaker, forcing out the air. Although you can't see it, you can pour CO2 gas out of the beaker just like you would pour a liquid. By way of teacher demonstration, a match can be lit and placed down into the gas. The match will be extinguished showing that the oxygen in the air has now been forced out, replaced by the carbon dioxide. Students can also feel the CO2 being poured out of the beaker because it's cold (similar to cold carbon dioxide gas coming out of a fire extinguisher). As the reaction with baking soda and vinegar is "endothermic," meaning that energy (as well as CO2) leaves the products during the reaction cold, care should be taken not to introduce any of the liquid into the bottle as it will continue to keep the temperature of the liquid depressed.

For Methane: As methane is lighter than air, simply invert the bottle over a gas jet in the lab and allow some gas to flow into the bottle for a few seconds. The gas jet needs only to be turned on for a few seconds to replace the air and fill the bottle.

SAFETY HAZARDS: This experiment calls for the use of classroom gas jets of methane (CH4), a flammable substance. The instructor should perform any and all preparations of natural gas samples for this experiment. It is absolutely crucial that the instructor be familiar with the state and district protocol and law for use, maintenance, and disposal of this substance. As natural gas can be ignited by a flame, extreme care should be taken to keep any lighted material away from the gas jet and bottle. Only the teacher should fill the bottles with methane, and only the closed bottle should be given to the student.

EQUIPMENT OPERATION

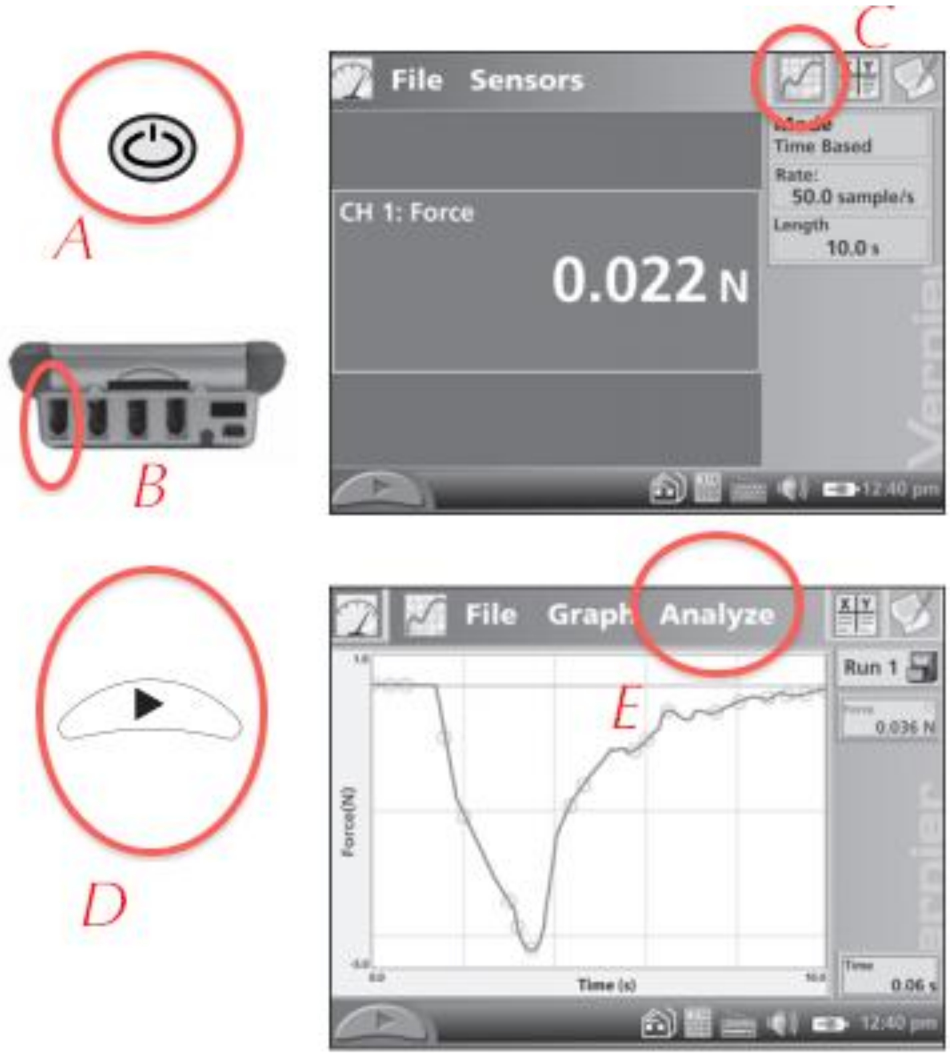

Figure 1: A sample LabQuest(R) screen with procedure instructions.

To begin using the experiment for this step, one needs only to power on the LabQuest™ unit by pressing the button labeled **A** in Figure 1. The apparatus should then change its display for collecting data using this accessory. If charged or connected to a power source, the screen will display its main menu. Connect the light sensor (distributed separately from the LabQuest™ unit) to one of the slots labeled **B.** A screen similar to the top image on the right-hand side of figure one should come up. Instead of force, however, temperature should be displayed. To change between Fahrenheit and Celsius, tap on the temperature reading with the LabQuest® stylus and select the desired scale from

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the drop down menu. To achieve the desired accuracy, students will need to tap on the icon labeled **C** to access the graph mode. A blank graph should be displayed. To record data, press the button labeled **D** on the face of the main LabQuest™ instrument. This will collect data from the **temperature probe** for ten seconds. If after ten seconds this feature does not stop automatically simply tap on the "stop" button on the lower left hand side of the screen as demonstrated on the included video in the above references.

The unit will display a graph of the temperature over ten seconds in a graph afterward. The students should then click on Analyze, labeled **E**, and then tap on **Statistics/Ch 1: Temperature Probe.** This will display basic statistical data including range, min, max, and **mean** on the right-hand side of the screen beside the graph. The students should record this value (**mean value)** as their collected data.

STUDENT OBSERVATION

Students should record their data in the **data sheet** (see Materials).

As the students are working, the following are some probing questions the instructor might ask independent groups as he or she walks among them:

- What do you notice about this instrument so far?
- How did your team decided to measure temperatures? Why did you agree this was the best way? Why do you disagree?
- Can you explain to me what you've found so far?
- Have you noticed any patterns in your data so far?
- What do you predict will happen over time?
- Do these numbers agree with what you expected? Why/why not?

Notes:

- The main feature of this experiment is the temperature measurements via the **temperature probe.** This instrument is specifically designed and calibrated for laboratory measurements such as these and is not limited to compatibility with the LabQuest™ units. See the manufacturer's website for other interfaces including CBL 2™.
- According to the user's manual, these probes need not be calibrated. See manual for calibration instruction in extreme situations.

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- This lesson plan assumes a class size of 24 subdivided into groups of three. This yields eight groups working on 4 different gas systems. It is recommended that two groups be assigned to each system.
- This section encourages collaborative learning, as students are assigned distinct roles in each group. These include operating scientific technology, properly using a thermal probe for accurate measurement, and recording data.
- I've modified this lesson to make use of the LabQuest®'s time series feature. Given the published sensitivity and precision of this probe, the students will measure the temperature of each sample in ten-second integrations and record the mean temperature for each run on their data sheets. This will be iterated once every minute for fifteen minutes and should be sufficient to reproduce the sample data trend from the USGS below.
- The instructions include the students discussing amongst themselves the best way to make temperature measurements for their sample. It is imperative that the instructor visits each group to check for proper thermometer/thermal probe use. That is, the probe should be not be touching the walls of the sample bottle nor the hands of the students. Also, the instructor should provide the necessary guidance for how far to hold each bottle from the incandescent light source (a foot or less is recommended by the USGS).
- The students are also asked to graph their data while taking measurements; the instructor should also check for understanding with each group should questions about scaling and plotting arise.

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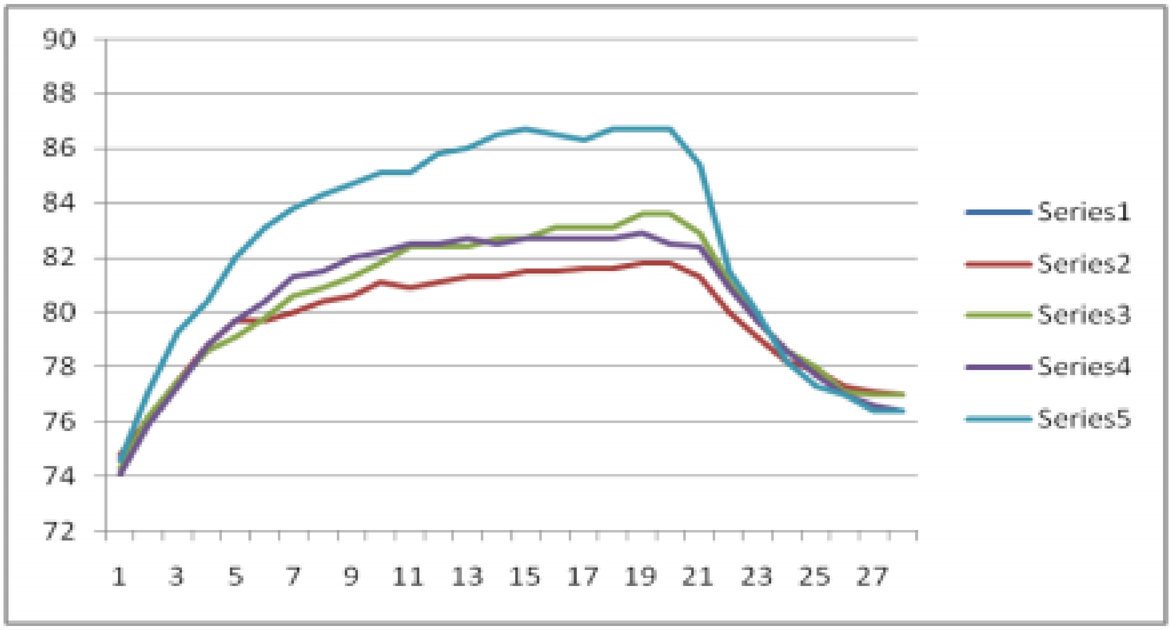

Figure 2: Sample data from the USGS. Series 2: Dry (air only), Series3: Water, Series 4: Carbon dioxide, Series 5: Methane. The horizontal axis is time in minutes, and the vertical axis is temperature in degrees Fahrenheit.

<u>EXPLAIN:</u>

After the allotted experiment time, the instructor should regain the students' attention for discussion. On the black/whiteboard or an overhead display, the teacher should write down key ideas from student responses to probing questions such as any of the following.

- What was the *maximum* temperature for your sample?
- How do the gases compare to each other? How can we identify any patterns?
- Which gas showed the most heating? Which showed the least?
  - How does this compare with your group's predictions?
  - How can we use our data to modify our educated guesses about these gases?
  - In the case of large systematic error, the instructor may wish to display a sample graph of his/her own or the provided USGS plot:
    - We find a discrepancy between our class measurements and my measurements. Where might these differences be coming from?
    - How can we verify which is more *accurate?*
    - How can we improve our measurements in future experiments?
- What happened after you turned off the lamp? And how do you know that?

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- What do you think would have happened if we took data for an even longer heating and cooling time?
    - Tell me more…..
    - Why do you think that would happen?
    - And if I changed (variable)? What might happen then?
- How are these bottles of gases similar and different from the atmosphere of the Earth?
- What about this light bulb? What is it doing?
    - What sort of light is it emitting?
    - Is it just visible light?
        - Incandescent bulbs radiate significantly in the infrared.
    - What's causing the temperature change that we notice?
- *Based on what we've measured in the lab **empirically,** how can we **apply** our new knowledge to larger systems (e.g. the atmosphere)?*
    - If necessary this is an opportunity to introduce the term empirical, or *relying or derived from observation or experiment*
- *What could be some physical (or chemical) reasons for the trends we have observed?*

Since these last questions are at the heart of this lesson, it may help to present or define (ideally, prompt the *students* first to mention and define these terms) any of the terms in the above **concepts** or **background sections (**but not those reserved for the following expansion section)**.**

ELABORATE:
There is a wealth of information contained in the IPCC's climate change reports (referenced and links to full documents with vector graphics above), but this section focuses on two of the most powerful graphics in the 2007 report.

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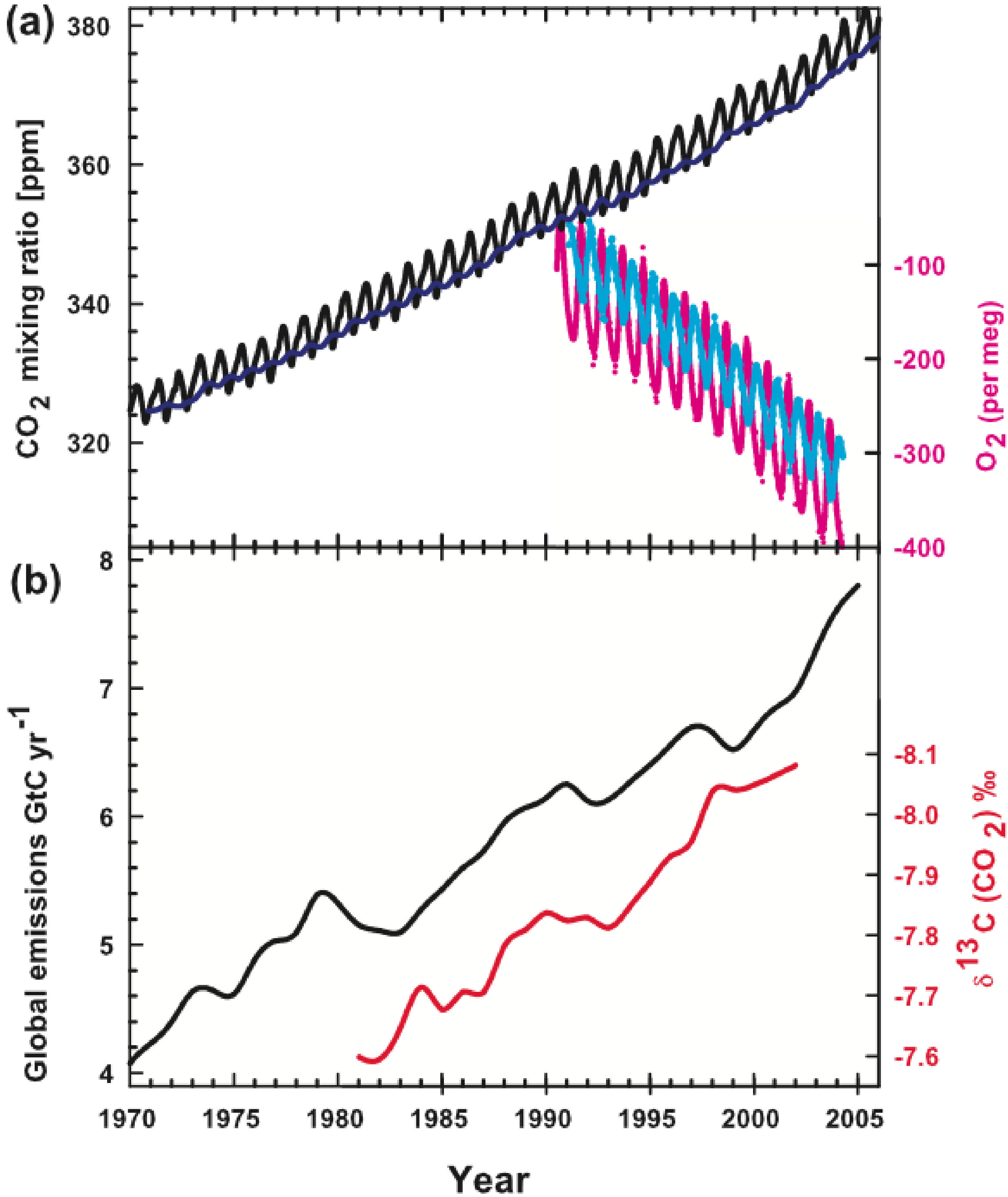

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Figure 3: Recent CO2 concentrations and emissions. (a) CO2 concentrations (monthly averages) measured by continuous analysis over the period 1970 to 2005 from Mauna Loa, Hawaii (19°N, black; Keeling and Whorf, 2005) and Baring Head, New Zealand (41°S, blue; following techniques by Manning et al., 1997). (b) More recent CO_2 global emissions vs. $^{13}C/^{12}C$ ratios (IPCC, 2007)

The top of this first plot contains the famous 'Keeling Curve,' which shows the increasing concentration of atmospheric carbon dioxide over Hawaii since 1958. The Keeling Curve was highlighted in Dr. David Orr's *Hot Science – Cool Talks* lecture (see Sources & Resources). The second plot contains recent global carbon dioxide emission data. The fact that the Carbon 13/Carbon 12 ratio simultaneously is dropping (axis reversed) provides strong evidence that fossil fuels and land clearance are primary sources for rising atmospheric carbon dioxide levels. See references for more details and supplemental plots on isotope plots.

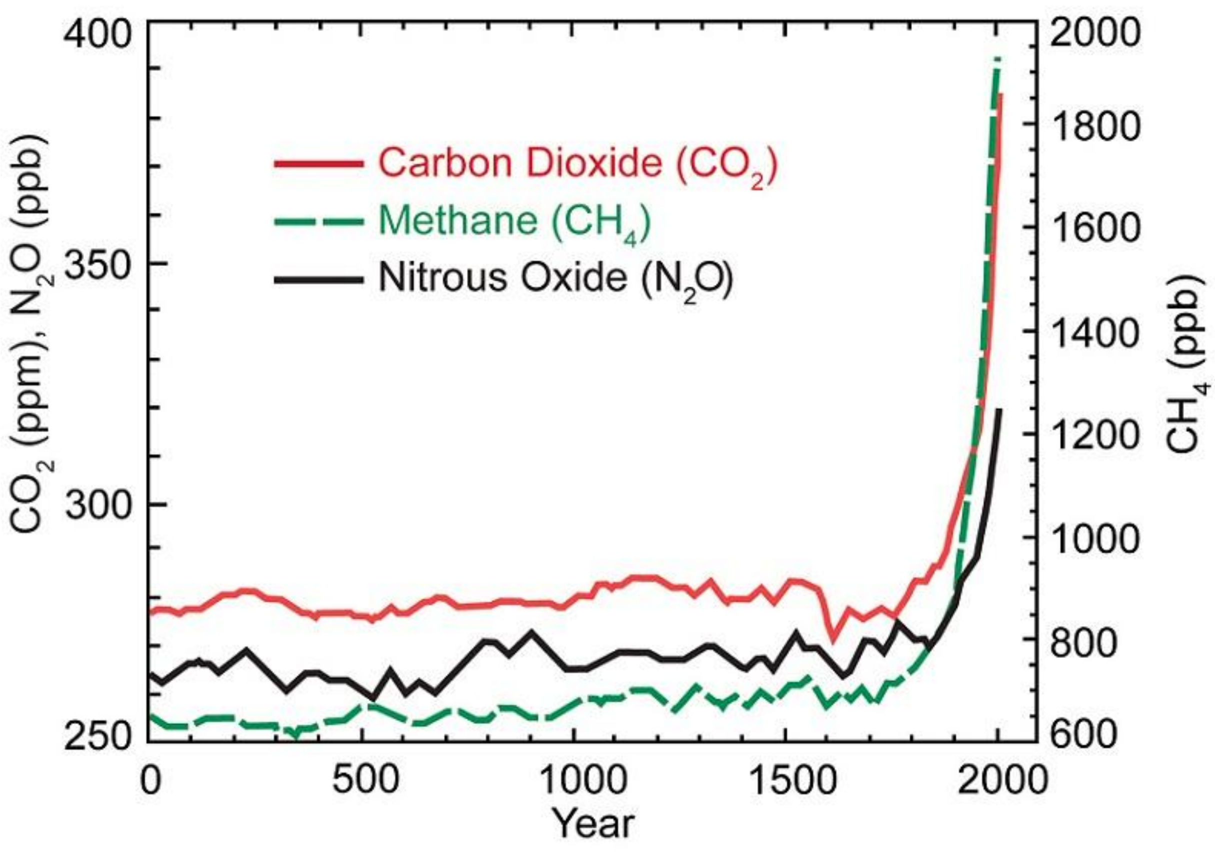

Figure 4: This graph shows the increase in greenhouse gas (GHG) concentrations in the atmosphere over the last 2,000 years. Increases in concentrations of these gases since 1750 are due to human activities in the industrial era. Concentration units are parts per million or billion molecules of air. Source: USGCRP (2009)

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Given these plots, it is important for the instructor to prompt the students to discuss among their groups what physical implications these increasing concentrations can (and do) have in the natural world. That is, given what has been already seen in the laboratory through their measurements, what can be induced about a complex a system as the earth's atmosphere by changing these concentrations? And, crucially, what physical processes *explain* these changes?

Although the science behind sophisticated climate measurements, units, and theories may seem daunting, the emphasis here is on the physics and chemistry at play between the Earth and the sun. As necessary, the instructor can provide the following insights for the students to come to their own conclusions.

- Where does the thermal energy from go after reaching the surface of the Earth?
  - This is implying that matter not only absorbs but also emits radiation.
  - In this case, the surface of the sun re-radiates in the *infrared*, the band of electromagnetic radiation that greenhouse gases are efficient at absorbing
- What exactly *is* a greenhouse? What purpose does it serve?
  - What is different about a greenhouse from the atmosphere of the Earth?
  - What exactly *is* the "greenhouse effect"? Is this even a good name for it in the case of the Earth? Why/why not?
  - What about in a car? Why does it *actually (*physically) get so hot when all of the doors are closed on a sunny day?
  - Is the greenhouse effect, *in itself,* a "bad" thing?
  - Do other planets exhibit this same effect?
    - The purpose of these questions is to introduce the discussion that indeed greenhouses function on the transmitting properties of glass as well as the density of hot and cold air to function. However, greenhouse gases, by their physical chemical nature are more effective at *absorbing*, and therefore 'trapping' more infrared radiation that would otherwise escape the earth's atmosphere. This affects the energy balance of the earth and leads to a net warming effect *similar* to how a car's windows prevent re-radiated infrared radiation to escape through glass.
    - Also, it should be noted in discussion that life is greatly dependent on the chemical properties of greenhouse gases in the atmosphere to retain heat and thereby serving as an *insulator.*

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- Although Venus is further than Mercury from the sun, it has the highest temperatures in the solar system due to its extremely thick atmosphere that traps gas via the same greenhouse effect mechanism.

o Are greenhouse (GHG) gases the only factor (variable) that can influence global temperatures? How do you think these compare to each other in their contributions? [Radiative Forcing]

- A possible introduction to the discussion of the energy balance of the earth and additional contributing factors such as albedo *and* the significantly larger radiative forcing contribution due to long-lived *greenhouse gases (GHG).*

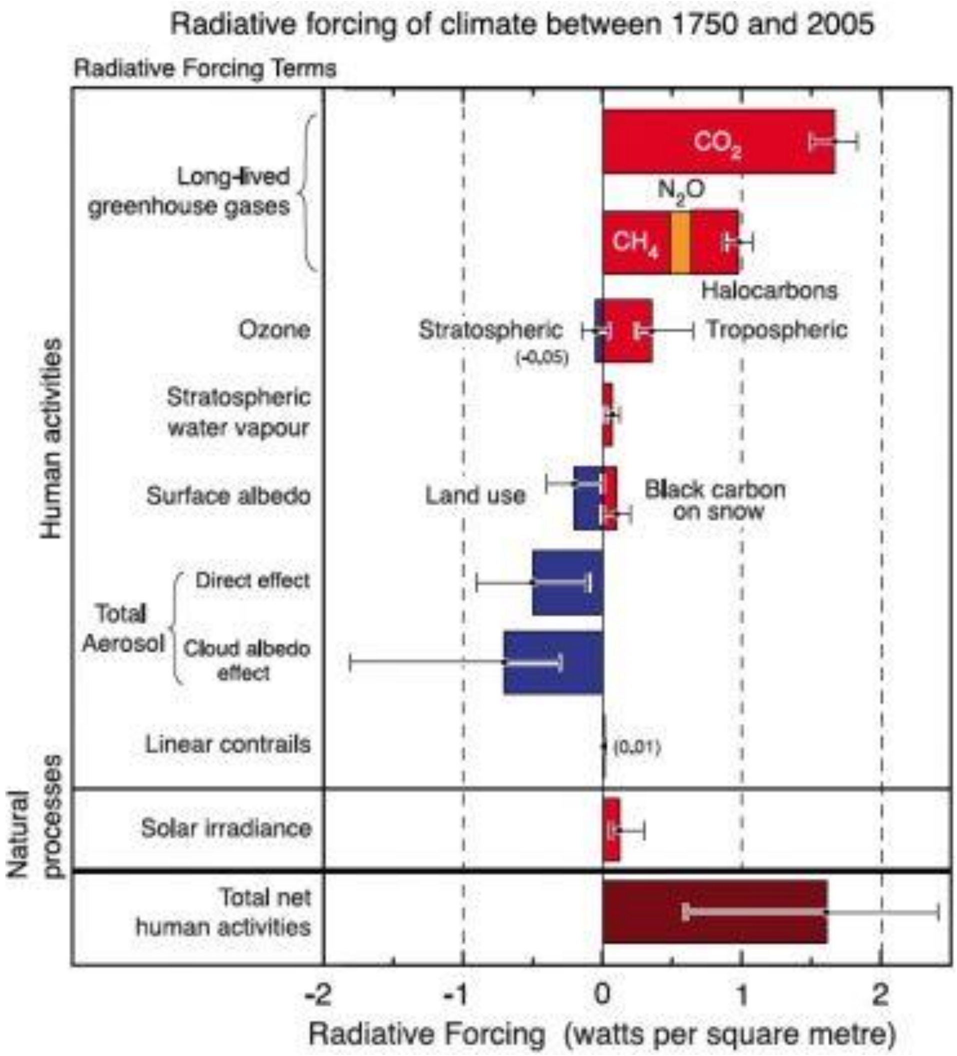

Figure 5: This summary chart from the IPCC's Fourth Assessment Report shows the main components of radiative forcing that affect the Earth's climate. The values represent the amount

these factors have changed (as of 2005) since 1750, in the pre-industrial era, along with corresponding uncertainties. (IPCC, 2007).

Clearly, there is a lot of freedom for instruction with so many available data, but the focus of this lesson is on the chemical properties of greenhouse gases that distinguish them from ordinary air. The students *empirically* observe this in the laboratory, and discussion should then build on not only the consequences for rising concentrations of these gases in the Earth's atmosphere, but also *why* these gases have the properties that they do.

EVALUATE:
See Materials for an objective-based **evaluation worksheet**.

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Infrared Investigations: GHG - Instructions

Roles

Hello, scientists! For this to be a successful experiment, you must work with your table members as a *team*. Each member will have a unique role. These include: *computer operator, sample manager, probe operator, and recorder).* These will be assigned based on your last name, **in reverse alphabetical order.** These are your duties for this experiment.

Computer Operator (last name closest to the end of the alphabet): Your job is to work the assigned LabQuest® instrument interface to collect data.

Probe Operator is responsible for properly handling the assigned thermal probe to make scientific measurements.

Recorder shall write down data for each sample tested and any other interesting patterns or trends your group notices.

Description

Assigned to your group is a sample of gas in a partially enclosed container. At your table is an incandescent light bulb to serve as a heat source. Your task is to collectively determine a way to systematically measure this gas's temperature over time.

Experiment Procedure

Probe Operator

One of the crucial components of any experiment is knowing how to properly measure a desired quantity. The supplied temperature probe will be your instrument for this experiment, but you must first discuss among your group members *how* you will use this for each measurement. That is, how will you hold the probe? How will you insert the probe into your system to measure temperature as accurately as possible? How far will you hold the probe/gas container from the light source (why?)?

The probe operator will be responsible for handling this instrument and preparing the system for measurement each time using your group's decision.

Computer Operator

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The **computer operator** will then click on the main button on the front side of the instrument (it looks like a 'play' button; your instructor should clarify prior to this). The instrument will record data for approximately ten seconds and produce a graph.

Tap on Analyze at the top of this screen and select statistics/Ch. 1 Thermal Probe

On the right-hand side of the screen, there should be several values such as min, max, and **mean.** This last one is what you are to measure.

Begin your measurements at the **room temperature** value. That is, your first measurement should be with the light source at your desk or table off.

Now, turn on the light source. After one minute, make another measurement and continue this process for nine minutes.

At the tenth minute, switch off your light source, and continue making measurements of your bottle each minute for ten more minutes.

You should be recording data for a total of twenty minutes.

Recorder

The **recorder** shall write down and graph each of these values on the data sheet.

Discuss with your team members what you have measured and what your data might be able to tell you about your samples. This also goes on back of the data sheet.

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Group Members :____

Gas Observed: __________________________

Time (minutes)	Temperature (ºC)
0 (room temp.)	
1	
2	
3	
4	
5	
6	
7	
8	
9	
10 (turn light off)	
11	
12	
13	
14	
15	
16	
17	
18	
19	
20	

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Infrared Investigations: GHG

Name : ____

1. What is **infrared** radiation, and how does it relate to the study of greenhouse gases?

2. In your own words, describe the **greenhouse effect.**

3. What is **radiative forcing** in relation to the study of global climate change? How do greenhouse gases contribute to this quantity?