Khan Academy

STUDENT ACTIVITY GUIDE

How do carbon dioxide and albedo affect how Earth interacts with sunlight?

The challenge

Electromagnetic radiation from the Sun interacts with Earth in complex ways. Two factors that affect the interactions are the greenhouse effect in Earth's atmosphere, and the different reflection and absorption properties of Earth's surface. These interactions have maintained a relatively stable climate throughout most of human history. But how do they work, and what happens if they're disturbed?

"The Sun shines above Earth's horizon" by NASA, Public domain

In this activity, you'll investigate the effect of carbon dioxide concentration and albedo on air temperature. Then, you'll analyze real-world data to explain how these factors are related via feedbacks, and how Earth's systems are being affected as a result.

By the end of this activity, I will be able to…

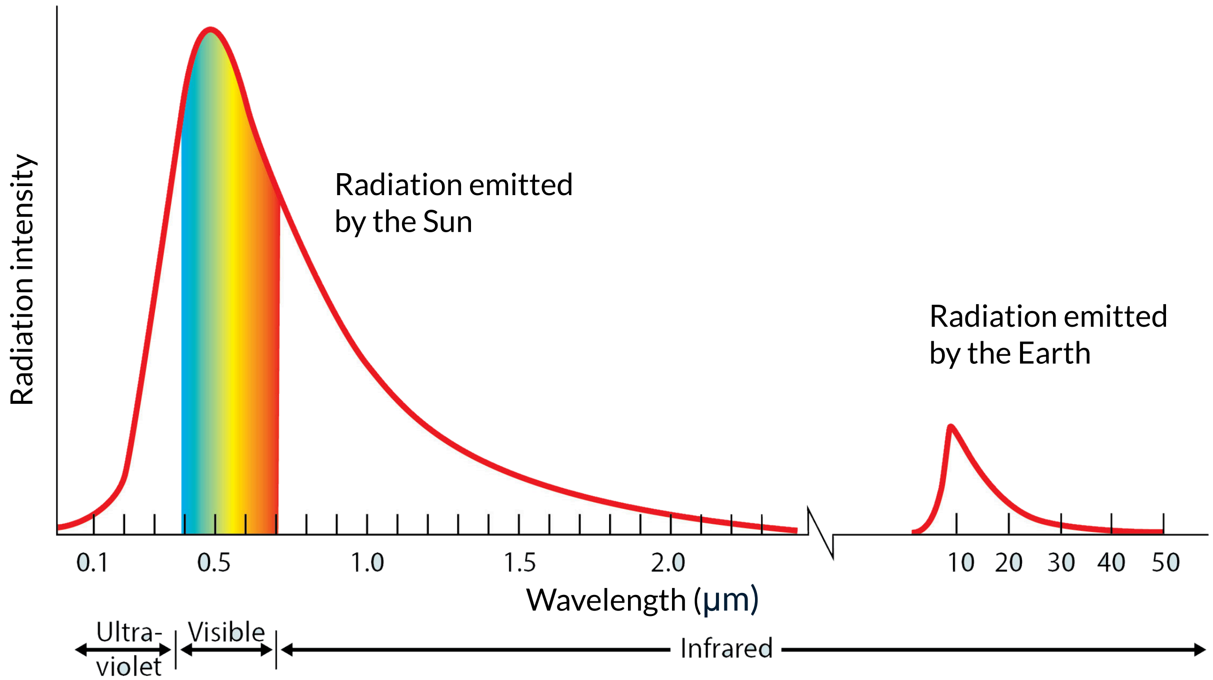
- explain how carbon dioxide and albedo affect interactions with light, and how those interactions are related to temperature.
- analyze data to determine how Earth's systems are affected when interactions with sunlight change.
- model how one change to Earth can create feedbacks that cause changes to other Earth systems.

Khan Academy

Setting the stage

A **blackbody** is a theoretical object that absorbs all electromagnetic radiation that shines on it. A blackbody in thermal equilibrium emits its own continuous electromagnetic spectrum. The peak wavelength emitted depends only on the blackbody's temperature.

The Sun and Earth can be approximated as blackbodies. The blackbody spectra emitted by both are modeled on the graph below.

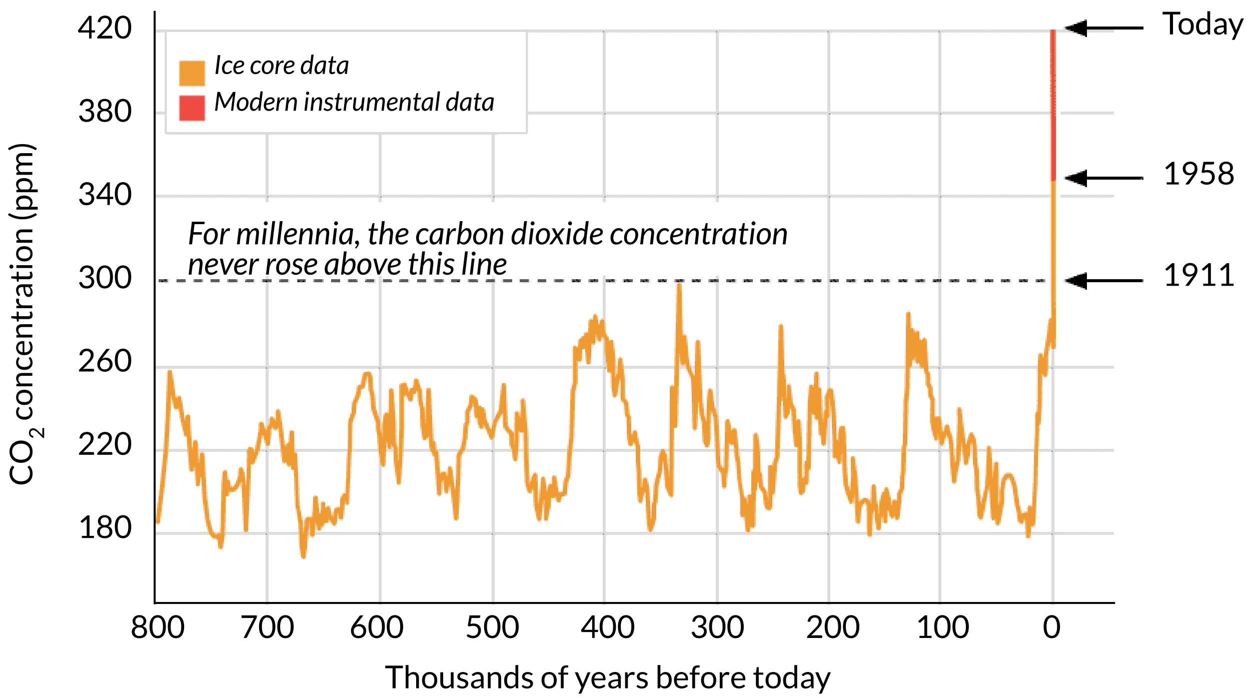


"Shortwave and longwave radiation of Earth and the Sun" by the UCMP, CC BY-NC-SA 4.0. Cropped from original.

The highest intensity radiation emitted by the Sun occurs in the ________________________ band of the spectrum. It also emits significant amounts of radiation in the ________________________ and ________________________ bands. Because Earth is much cooler than the Sun, it emits radiation primarily in the ________________________ band of the spectrum. We typically associate this band of the spectrum with **heat**.

Without an atmosphere, energy lost from Earth via radiation would result in an average surface temperature around -18 °C. But fortunately for us, the greenhouse effect in Earth's atmosphere raises the planet's average temperature to a more habitable 15 °C.

The **greenhouse effect** occurs because certain gases in the atmosphere absorb and re-emit infrared radiation, trapping heat. These gases include methane, water vapor, and carbon dioxide. The graph below shows the concentration of carbon dioxide in Earth's atmosphere over the last 800,000 years. *(Note: Data from before the modern age was collected via ice core samples.)*



NASA, Public domain

The graph shows natural variations in atmospheric carbon dioxide concentration over hundreds of thousands of years. However, an *anomaly* in the data appears around the year ______________________________ . Since this time, atmospheric carbon dioxide levels have ____, and the trend continues today. The change in CO_2 patterns is due to **human activities**, in particular the burning of fossil fuels, the destruction of forests and other carbon-sequestering ecosystems, and the expansion of industrialized agriculture.

However, atmospheric composition is not the *only* factor that affects Earth's climate. Another important factor is albedo. **Albedo** is the fraction of sunlight that a surface reflects. A surface that reflects a large fraction of sunlight has a (circle one) **high / low** albedo. A surface that reflects a small fraction of sunlight has a (circle one) **high / low** albedo. Consider the two surfaces shown below.

Snow-covered tundra

Parking lot

How do you think the albedo of each of these landscapes compares? Which surface would absorb more radiation from the Sun? Explain your reasoning.

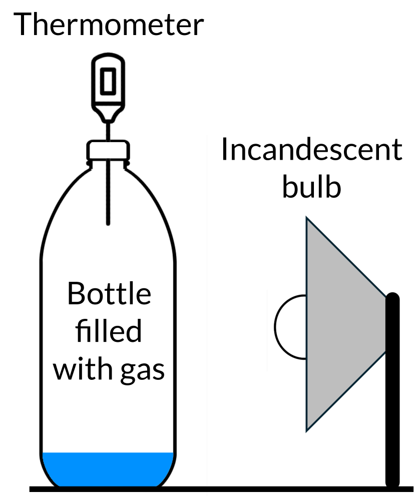
Now, let's investigate for ourselves how CO_2 concentration and albedo affect light interactions and temperature.

Let's get started!

Materials

- 75 to 200 watt incandescent bulb
- Utility lamp
- Two 2 L plastic bottles, with small holes punched in the caps
- One large wide-mouthed jar, with a small hole punched in the lid
- Ruler
- Digital thermometer
- Timer
- Effervescent tablets
- 1000 mL of water
- Black and white construction paper
- Tape

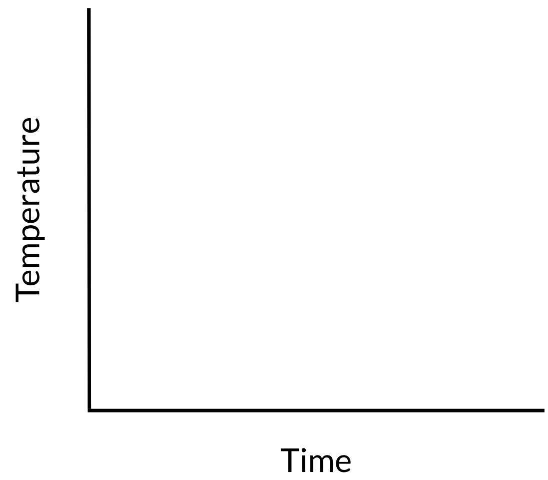
Investigation (Part 1)



To investigate the effect of carbon dioxide concentration on temperature, we'll simulate two atmospheres. Clear plastic bottles will be placed in front of an incandescent bulb that represents sunlight. One bottle will contain water and air. Another bottle will contain water and air, with effervescent tablets added. The tablets will add extra carbon dioxide gas into the bottle through the chemical reaction:

$$3\,NaHCO_3 + C_6H_8O_7 \rightarrow Na_3C_6H_5O_7 + 3\,CO_2 + 3\,H_2O$$

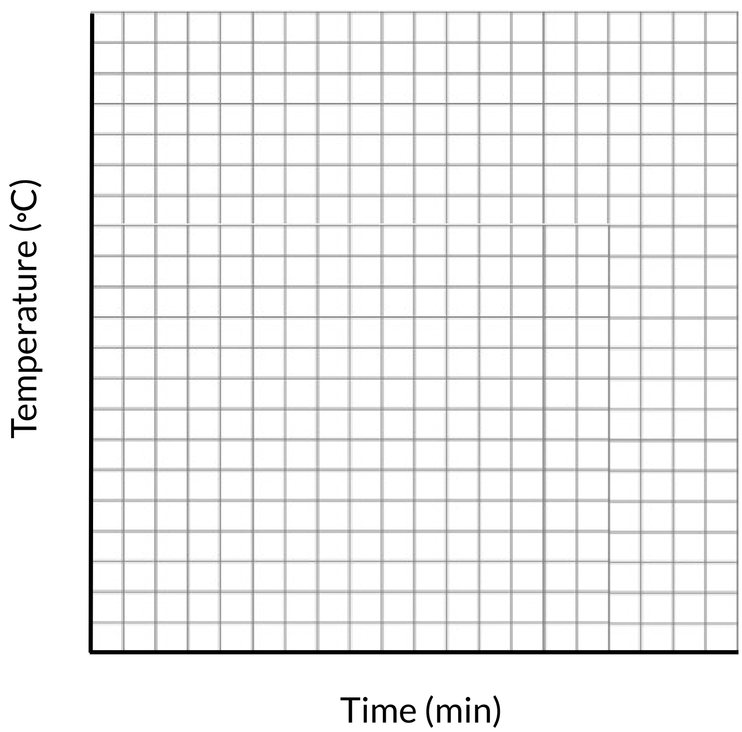
The temperature inside each bottle will be recorded over 16 minutes. How do you think the temperature inside each jar will change over time? On the graph, **sketch your prediction** for how the temperature of each bottle will change over 16 minutes. Use a different color or style of line to represent each bottle.



Procedure

1. Add 500 mL of room-temperature water to each bottle. Label one bottle "*Air*" and the other "*Extra CO_2*".
2. Add two effervescent tablets to the *Extra CO_2* bottle. Quickly cap each bottle. Place tape over the hole in the *Extra CO_2* bottle's lid to prevent gas from escaping.
3. Insert the thermometer into the hole in the *Air* bottle. Use tape to cover any gaps around the thermometer. *Make sure the thermometer does not touch the side of the bottle.*
4. Set up the utility lamp so it shines horizontally.
5. Place the *Air* bottle in front of the lamp 15 cm from the lamp. For bulbs with a wattage higher than 100 W, place the bottle 25 cm from the bulb.
6. Adjust the lamp so that it shines directly at the middle of the bottle.
7. Record the initial temperature of the bottle. Turn on the lamp, and begin the timer.
8. Record the temperature every two minutes for the next 16 minutes.
9. Repeat steps 5-8 for the *Extra CO_2* bottle. Make sure the bottle is the same distance from the bulb.
10. Plot both sets of data on the graph. Include a key.

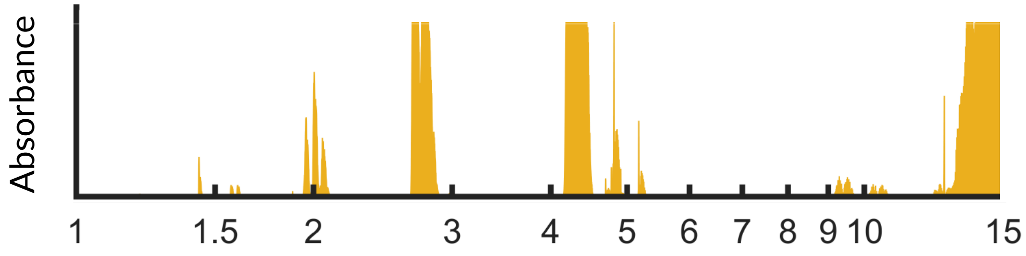
Time (min)	Air temp (°C)	Extra CO_2 temp (°C)
0		
2		
4		
6		
8		
10		
12		
14		
16		



Follow-up questions

1. Analyze your data. How did the final temperatures of the two bottles compare?

2. Carbon dioxide affects temperature because it absorbs specific wavelengths of electromagnetic radiation. The spectrum below shows the wavelengths absorbed by CO_2 molecules (on a logarithmic scale). The wavelength ranges of the electromagnetic spectrum are included for comparison.

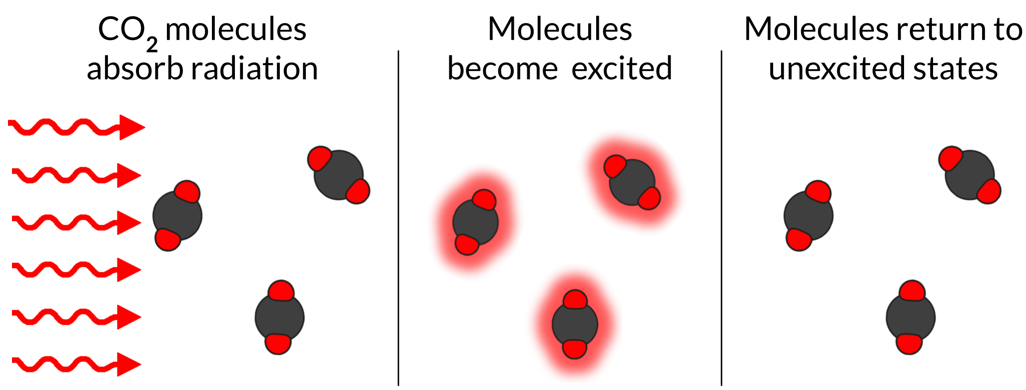


NIST, Public domain

Radio	Microwave	Infrared	Visible	Ultraviolet
>1.0 m	1.0 mm -1.0 m	.70 μm - 1.0mm	.38 μm - .70 μm	.24 μm - .38 μm

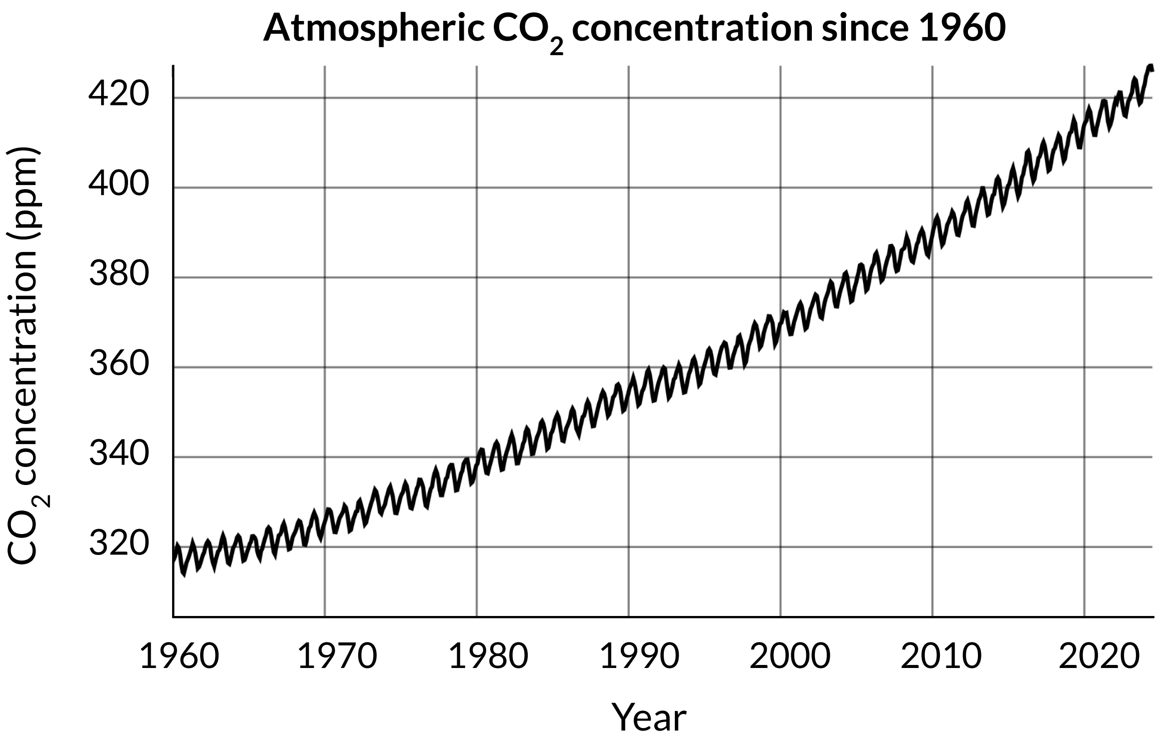
Approximately which four wavelengths shown are absorbed most by CO_2? In which portion of the electromagnetic spectrum are these wavelengths found?

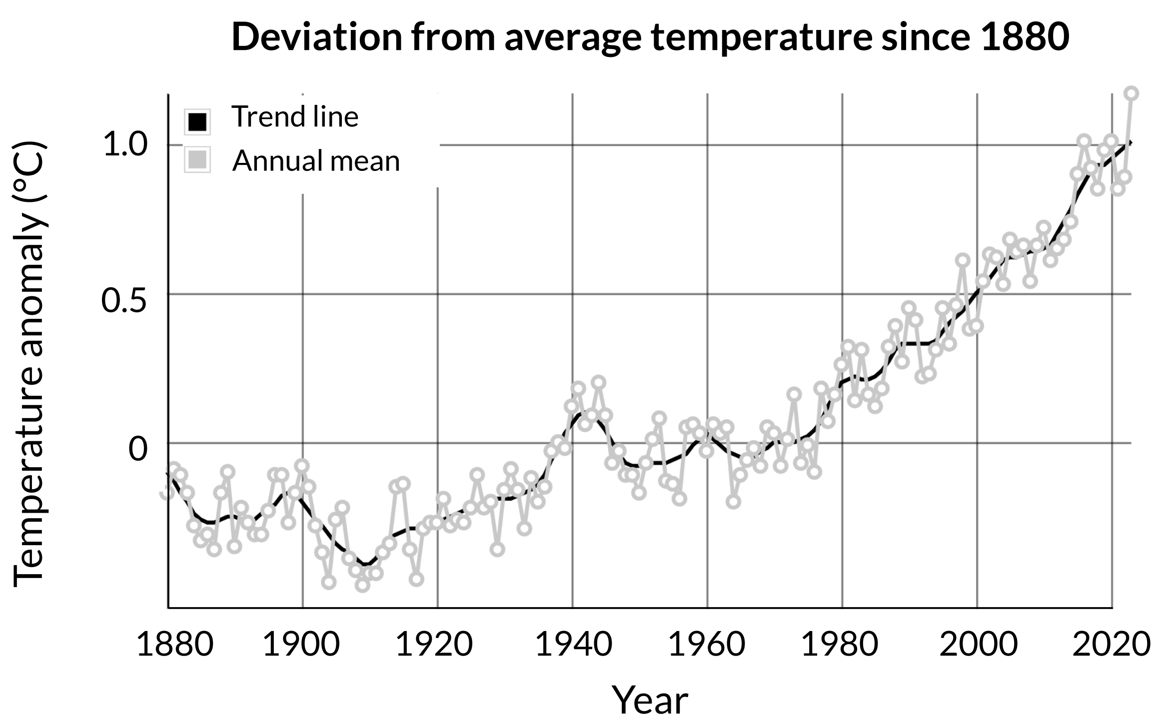
3. CO_2 molecules become *excited* when they absorb infrared radiation. When returning to an *unexcited* state, the molecules emit radiation in all directions at wavelengths of about **15 µm** and **4.3 µm**. This process is modeled below. Complete the model by sketching arrows to represent the radiation emitted when CO_2 molecules return to an unexcited state.



4. If the radiation emitted by excited CO_2 molecules encounters more CO_2 molecules, what will happen to it? How does this explain the bottles' different temperatures?

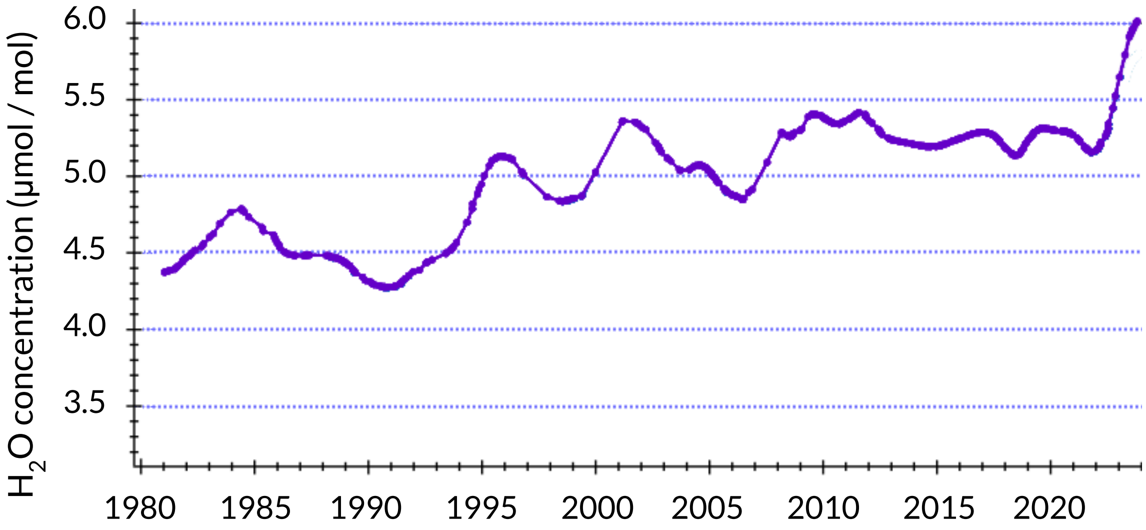
5. Analyze the following two graphs. How does the data relate to your findings from the investigation?





NASA and NOAA, Public domain

6. **Water vapor** is another greenhouse gas that absorbs infrared radiation. Water vapor is added to the atmosphere as liquid water evaporates. The graph below shows the concentration of water vapor in the upper atmosphere over Boulder, Colorado since 1980.

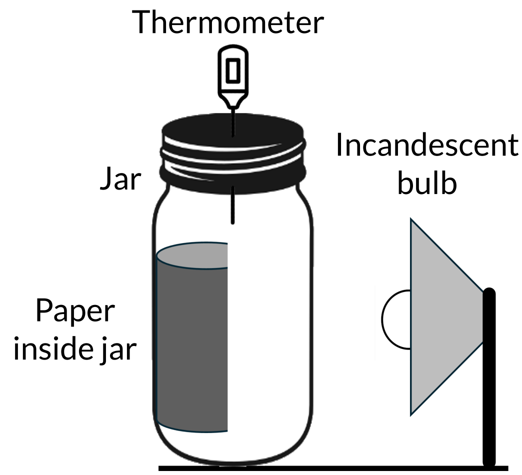


NOAA, Public domain

Positive feedback occurs when one change in a system leads to further changes that continue and exacerbate the original change. Describe why a positive feedback loop occurs between carbon dioxide, temperature, and water vapor in Earth's atmosphere. Sketch and label a simple model of this feedback loop.

Investigation (Part 2)

Next, let's investigate the effect of albedo on temperature. The inside of a jar will be covered with white paper. The jar will be placed in front of the bulb and the air temperature tracked for 10 minutes. Then, the process will be repeated with black paper inside the jar.

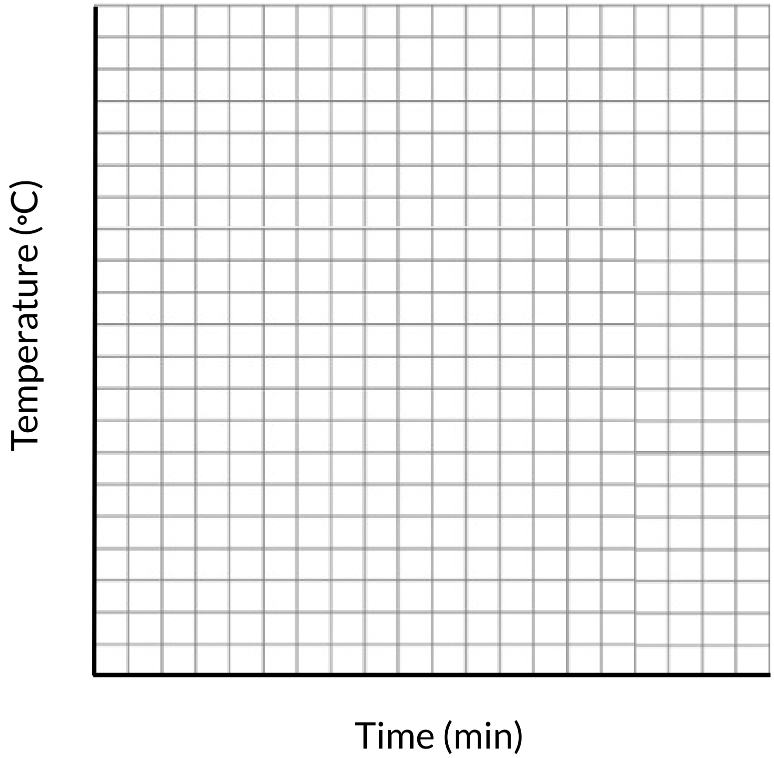


Predict how the final temperatures in the two cases will compare. Explain your reasoning.

Procedure

1. Place the piece of white paper into the jar. Press the paper flat against the wall of the jar so it covers at least half of the surface area inside the jar. Use tape to attach the paper if necessary.
2. Place the lid on the jar. Insert the thermometer through the hole. Use tape to cover any gaps around the thermometer. *Make sure the thermometer does not touch the side of the jar.*
3. Place the jar in front of the lamp 15 cm from the bulb. For bulbs with a wattage higher than 100 W, place the jar 25 cm from the bulb.
4. Adjust the lamp so that it shines directly at the middle of the jar.
5. Record the initial temperature inside the jar. Turn on the lamp, and begin the timer.
6. Record the temperature every minute for the next 10 minutes.
7. Replace the white paper with black paper. Repeat steps 2-6. Make sure the bottle is the same distance from the bulb.
8. Plot both sets of data on the graph. Include a key.

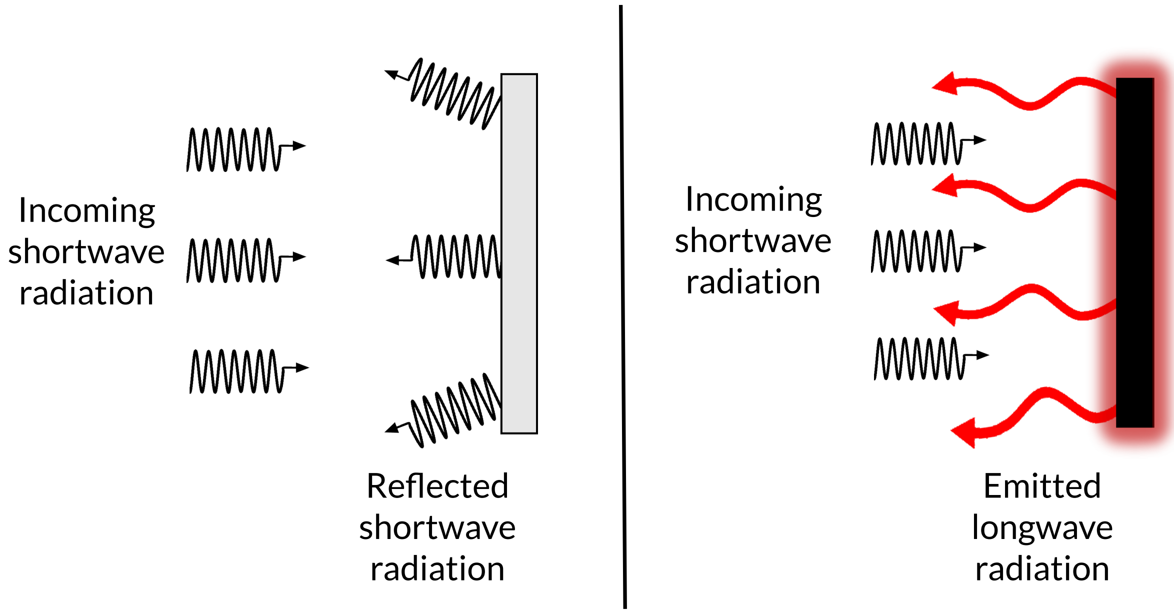
Time (min)	High albedo temp (°C)	Low albedo temp (°C)
0		
1		
2		
3		
4		
5		
6		
7		
8		
9		
10		



Follow-up questions

1. How does the albedo of a surface affect the surrounding air temperature? Support your claim with evidence from the investigation.

2. Use the model below to help explain how the different colored surfaces affect the temperature inside the jar.



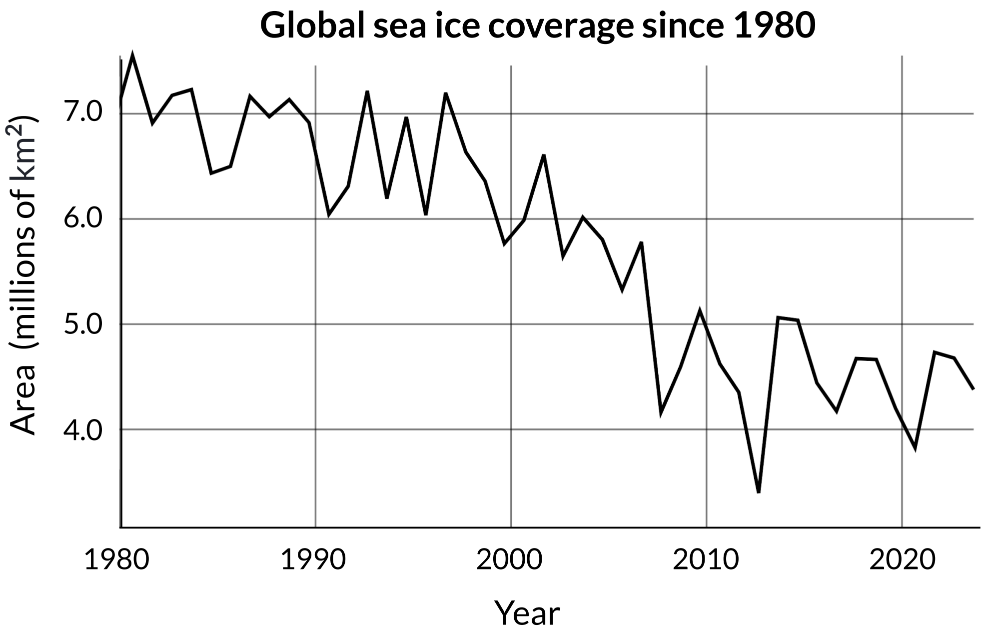
When shortwave radiation (visible light) from the bulb reaches the white surface, a large fraction of it is ___________________________. When shortwave radiation from the bulb reaches the black surface, a large fraction of it is ________________________. The radiation is re-emitted as ___________________________ radiation in the ___________________________ portion of the spectrum.

Use the model above to explain the results of your jar investigation.

3. How do the results of your investigation help explain how different surfaces on Earth—such as snow, glaciers, oceans, cities, and exposed soil—affect the planet's temperature?

4. How might changes in these surfaces, such as melting ice or urban expansion, impact local and global temperatures over time?

5. Sea ice coverage since 1980 is shown on the graph below.



NASA and NOAA, Public domain

Based on this data and what you've learned, describe why a positive feedback loop occurs between temperature Earth's overall albedo. Sketch and label a simple model of this feedback loop.

Keep creating!

Climate change impacts are visible across the planet, affecting several Earth systems as rising global temperatures trigger feedback loops. Research recent events around the world that have occurred due to climate change. Select an event to highlight in a social media post. Include images and first-person accounts from people directly affected by the event. Profile at least one solution that could prevent similar damage from happening in the future.

More creative ideas!

- **Permafrost** is ground that remains frozen for long periods of time. In recent years, an increasing amount of long-frozen Arctic permafrost has started to thaw. This thaw leads to damaged infrastructure and coastal erosion. Additionally, the thaw has the potential to trigger additional climate feedbacks. Research the potential impacts of thawing permafrost and how it could lead to a climate feedback. Then, create a model of the positive feedback loop triggered by this thaw.

- Urban areas are often warmer than the surrounding areas due to the **urban heat island** effect. Select a large urban city area near you, as well as a nearby city which is less developed. Locate temperature data for both cities over a time period of your choosing that clearly illustrates the urban heat island effect. Create a presentation for the urban city council about the heat island. Include the temperature data, an explanation of why the heat island occurs, the problems it causes, and at least one detailed project the council could implement to reduce the heat island effect.