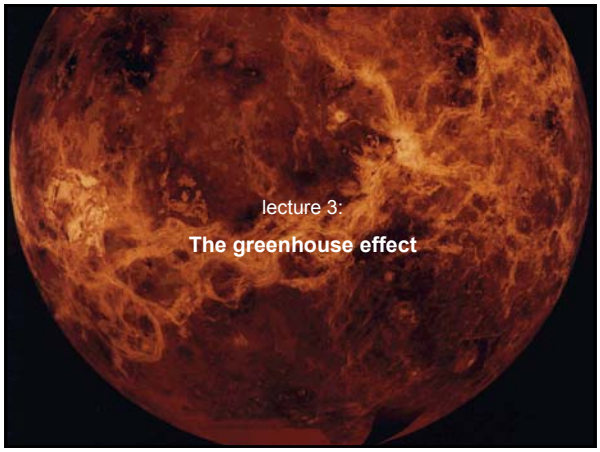
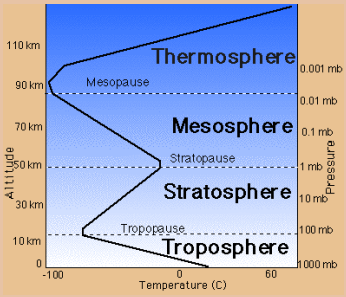



**Other concepts from Lecture 2**

- **Temperature Scales**
- **Forms of Heat Transfer**
- **Electromagnetic Spectrum**
- **Stefan-Boltzmann Law**
- **Reflectivity or Albedo**
- **Solar and Terrestrial Radiation**
- **Inverse Square Law**

## Thermal structure of the atmosphere




Keep in mind: 90% of the atmosphere's mass is in the troposphere.

## The greenhouse effect of Venus

From geometry, we can calculate the average solar flux over the surface of Venus. It is approximately **661 W/m$^2$**.

Venus is very reflective of sunshine. In fact, it has a reflectivity (or albedo) of 0.8, so the planet absorbs approximately 661 X 0.2 = **132 W/m$^2$**.

By assuming that the incoming radiation equals the outgoing radiation (**energy balance**), we can convert this into an effective radiating temperature by invoking the Stefan-Boltzmann law (total energy = $\sigma T^4$). We find that **T=220K**.

But Venus' surface has a temperature of **730K**!!!

The explanation for this huge discrepancy is the planet's greenhouse effect.

## The greenhouse effect of Earth

From geometry, we can calculate the average solar flux over the surface of Earth. It is approximately **343 W/m$^2$**.

The earth has a much lower albedo than Venus (0.3), so the planet absorbs approximately 343 X 0.7 = **240 W/m$^2$**.

By assuming that the incoming radiation equals the outgoing radiation, we can convert this into an effective radiating temperature by invoking the Stefan-Boltzmann law (total energy = $\sigma T^4$). We find that **T=255K**.

Earth's surface has a temperature of **288K**

While much smaller than Venus' greenhouse effect, earth's is crucial for the planet's habitability. Without the greenhouse effect, the temperature today in Los Angeles would be about 0 degrees Fahrenheit.

## Main Constituents of the Earth's Atmosphere

| | |
|---|---|
| Nitrogen | 78% |
| Oxygen | 21% |
| Argon | 1% |
| Water Vapor | 0-4% |
| Carbon Dioxide | 0.036% (increasing) |

Nitrogen, Oxygen, and Argon hardly interact with radiation. On the other hand water vapor and carbon dioxide both interact with infrared radiation---the type emitted by the earth and its atmosphere.

A greenhouse gas is defined as a gas that absorbs significantly the radiation emitted by the earth and its atmosphere.

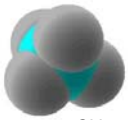
**Important Greenhouse Gases**

(concentrations in parts per million volume)

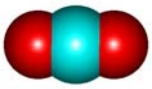
| | |
|---|---|
| water vapor | 0.1-40,000 |
| carbon dioxide | 360 |
| methane | 1.7 |
| nitrous oxide | 0.3 |
| ozone | 0.01 |
| chlorofluorocarbons | ~0.0007 |

**Why do certain gases interact with radiation?**

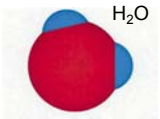
When radiation impinges on a molecule, it can excite the molecule, either by vibrating or rotating it. Molecules of a particular kind of gas have a different shape from molecules of another type of gas, and so are excited by radiation in different ways.



$CH_4$

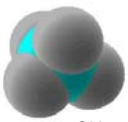


$CO_2$

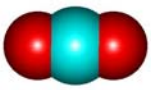


$H_2O$

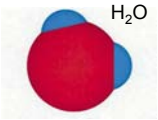
Because of their varying geometries and sizes, different molecules absorb radiation of different wavelengths. For example, $CO_2$ tends to absorb radiation of a wavelength of 15 microns (this wavelength excites bending vibration of the $CO_2$ molecule), whereas $H_2O$ tends to absorb at wavelengths around 12 microns (rotation of the $H_2O$ molecule) .



$CH_4$

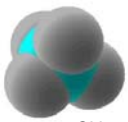


$CO_2$

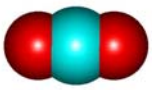


$H_2O$

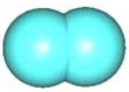
Molecules with more than two atoms tend to absorb radiation more effectively than diatomic molecules such as $N_2$ and $O_2$. This is because the more atoms a molecule contains, the more ways it can vibrate and rotate. This is why diatomic nitrogen and oxygen are not greenhouse gases.



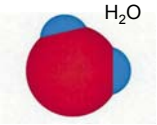
$CH_4$



$CO_2$

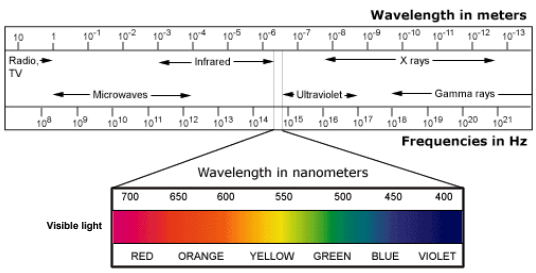


$O_2$

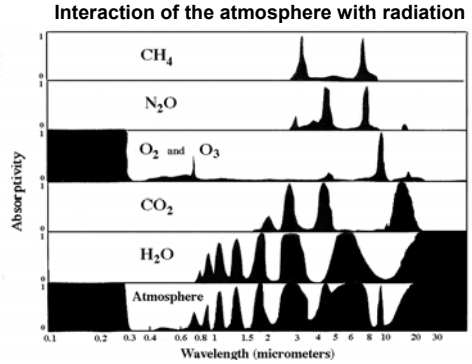


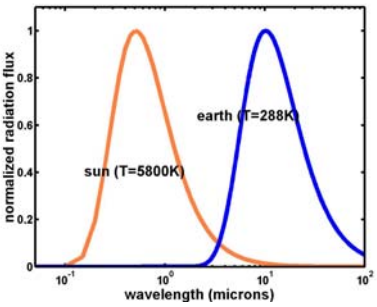
$H_2O$

The various forms of radiation are organized according to their wavelengths (and hence energy levels), creating the **electromagnetic spectrum**.



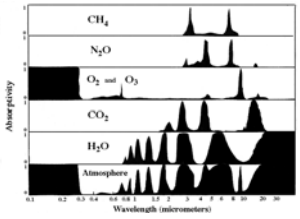

**Interaction of the atmosphere with radiation**






Note that the separation between the solar and terrestrial spectra occurs at about 2 microns

So how does this create a greenhouse effect? The greenhouse effect occurs because the atmosphere is relatively transparent to the wavelengths of solar radiation, while it absorbs infrared radiation. So a large chunk of the sun's radiation makes it to the earth's surface. At the same time, the atmosphere containing greenhouse gases absorbs the radiation emitted by the earth's surface, and re-emits it back to the surface, increasing the total energy the surface receives. This forces the earth's surface to become warmer than it would be otherwise.




**The greenhouse effect is a naturally-occurring phenomenon on the earth as it is on Venus. The <u>enhancement</u> of this effect by increasing greenhouse gases is the reason for concern about climate change.**