CHEM 103: Chemistry in Context

Unit 4.2

Atmospheric Chemistry:

the chemistry of global climate change

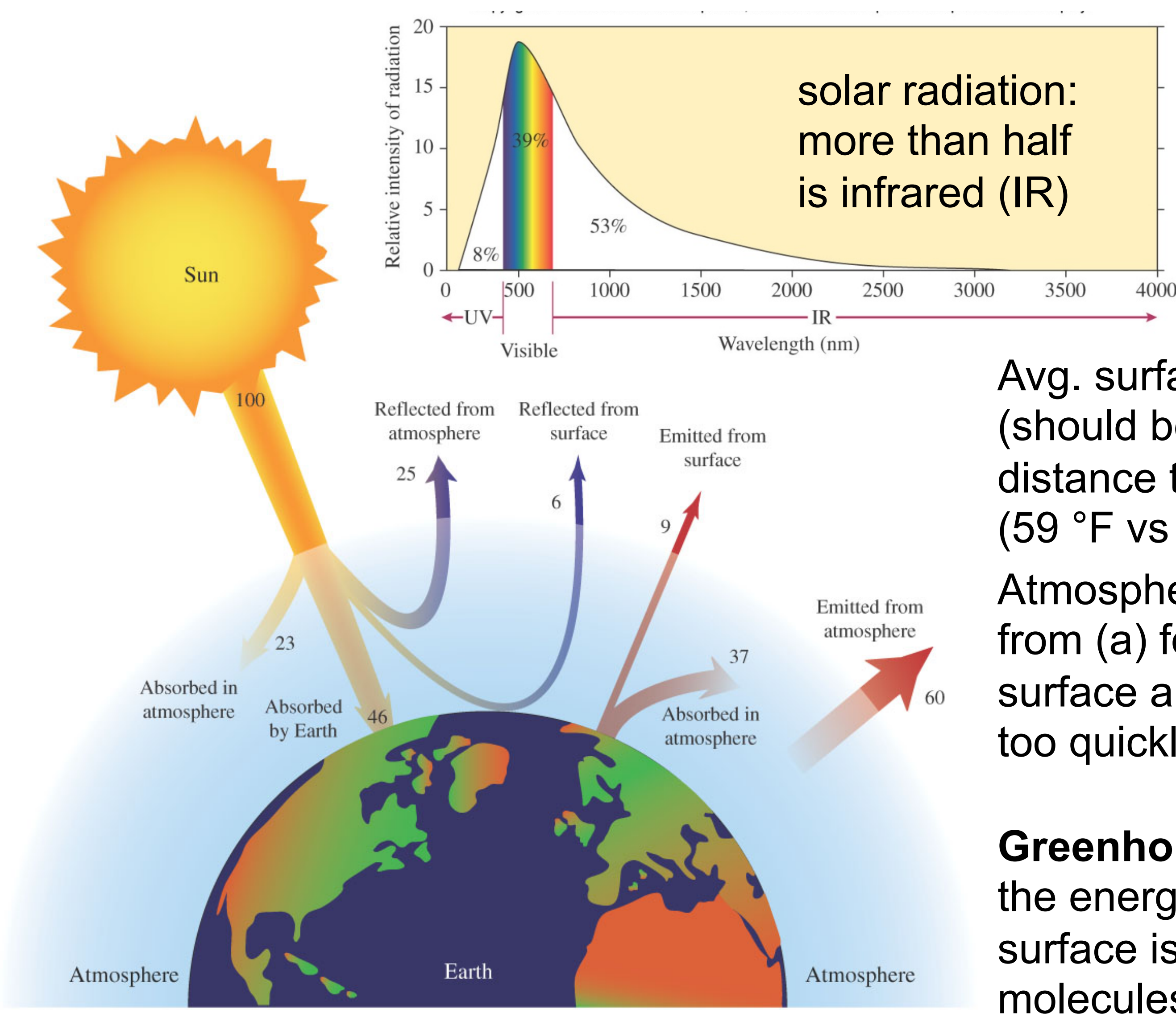
Reading: Chapter 3

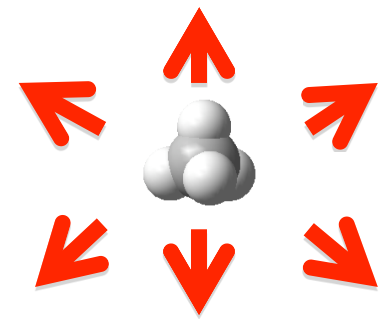
Colorado State University

Unit 4.2: Chemistry Behind Global Climate Change

- Solar energy balance
  - Earth's surface temperature should be -18 °C based on distance to the sun
  - Energy in = energy out
  - Greenhouse effect--definitions
- Infrared (heat) energy
  - Relationship to molecular vibrations
  - How the shape of molecules determines absorption of IR photons
    - change in molecular dipole needed for a molecule to absorb any kind of light energy
- Carbon cycle
  - need to get quantitative: review mass; introduce the mole as a really big number
  - use balanced chemical equations and unit analysis to determine things like the amount of carbon put into the atmosphere
  - natural forcings vs anthropogenic forcings
  - greenhouse gases
- Climate models
  - difference between correlation and causation
  - scientific arguments about theories versus legal/political debates
    - role of uncertainty in scientific theories and debate
    - ad hominem vs evidence/fact based arguments

Solar Energy Balance



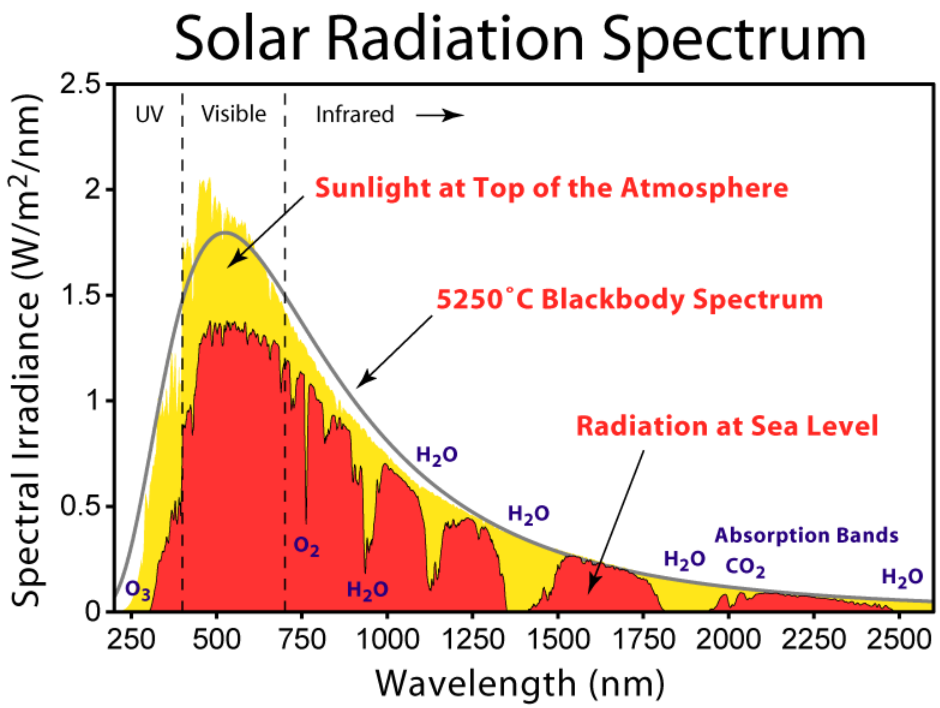


Avg. surface T on Earth = 15 °C (should be -18 °C based on distance to the Sun) (59 °F vs 0 °F)

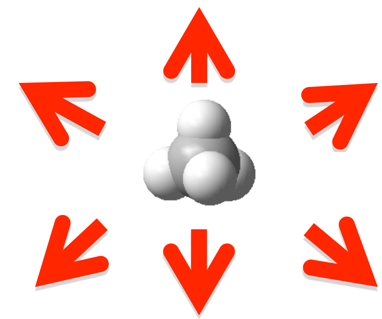
Atmosphere keeps solar energy from (a) focusing only on earth surface and (b) leaving Earth too quickly

Greenhouse effect: ~80 % of the energy emitted from Earth's surface is absorbed by molecules in the atmosphere

Greenhouse effect, Solar Spectrum

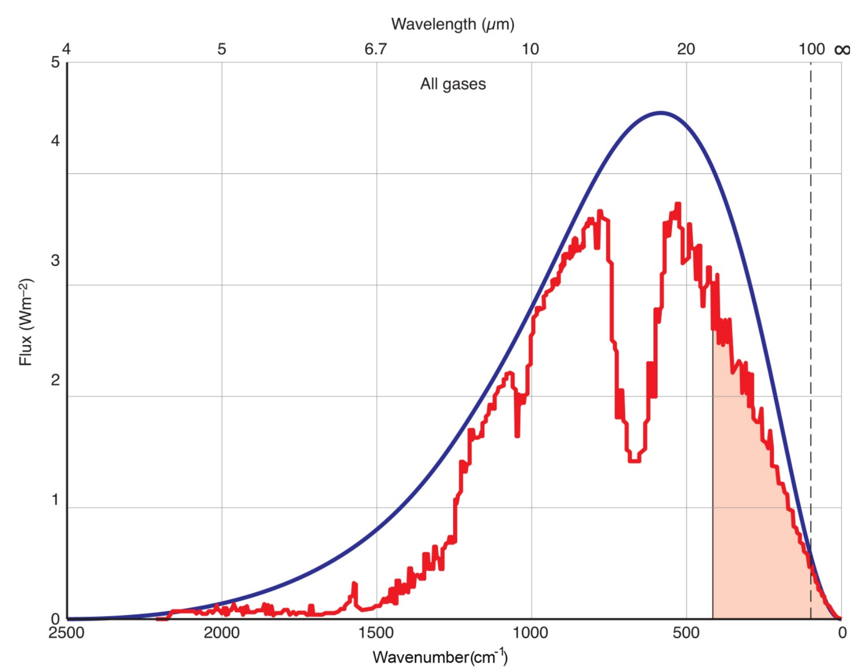


Light in



Light out

1μm=1000 nm



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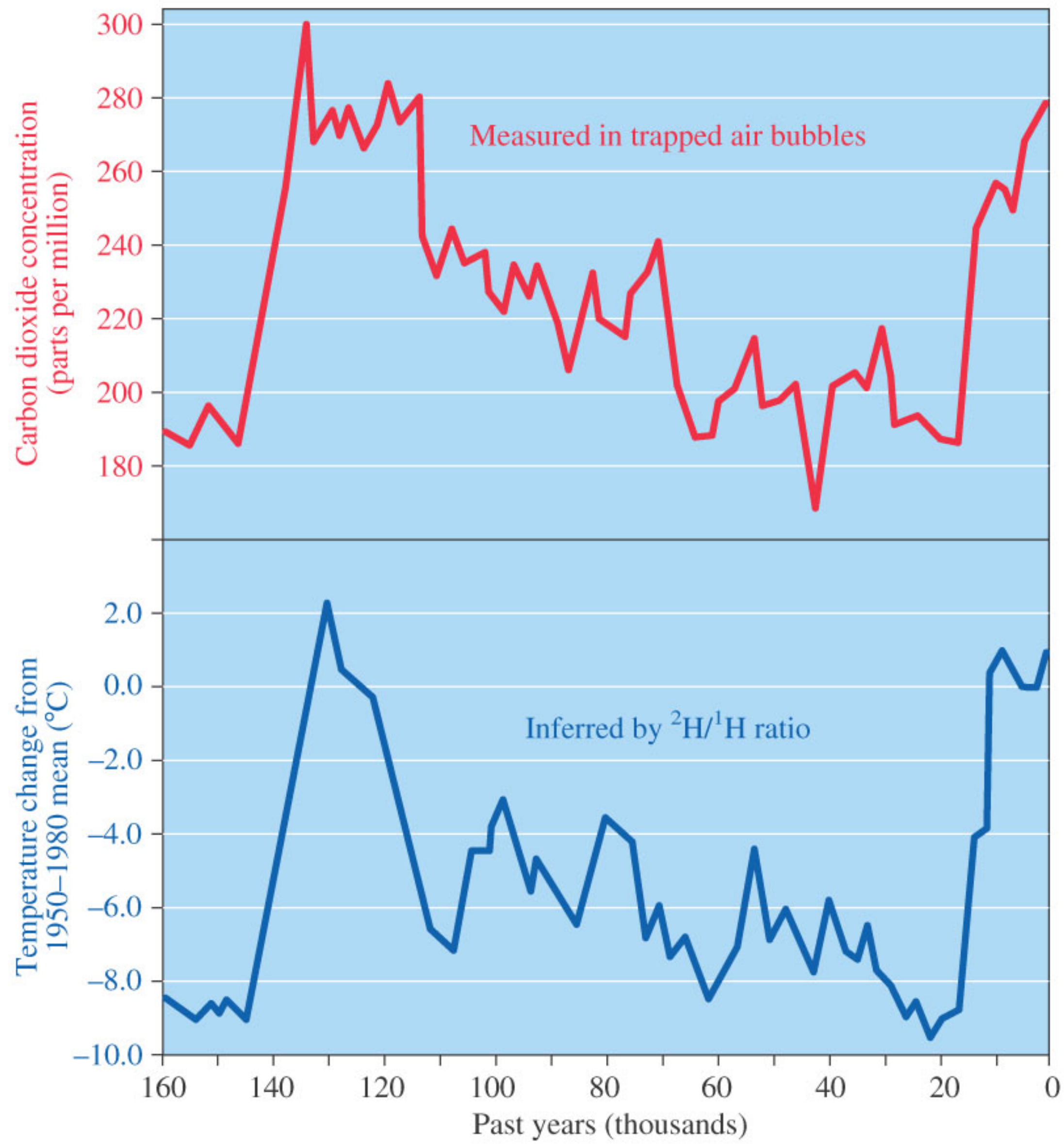
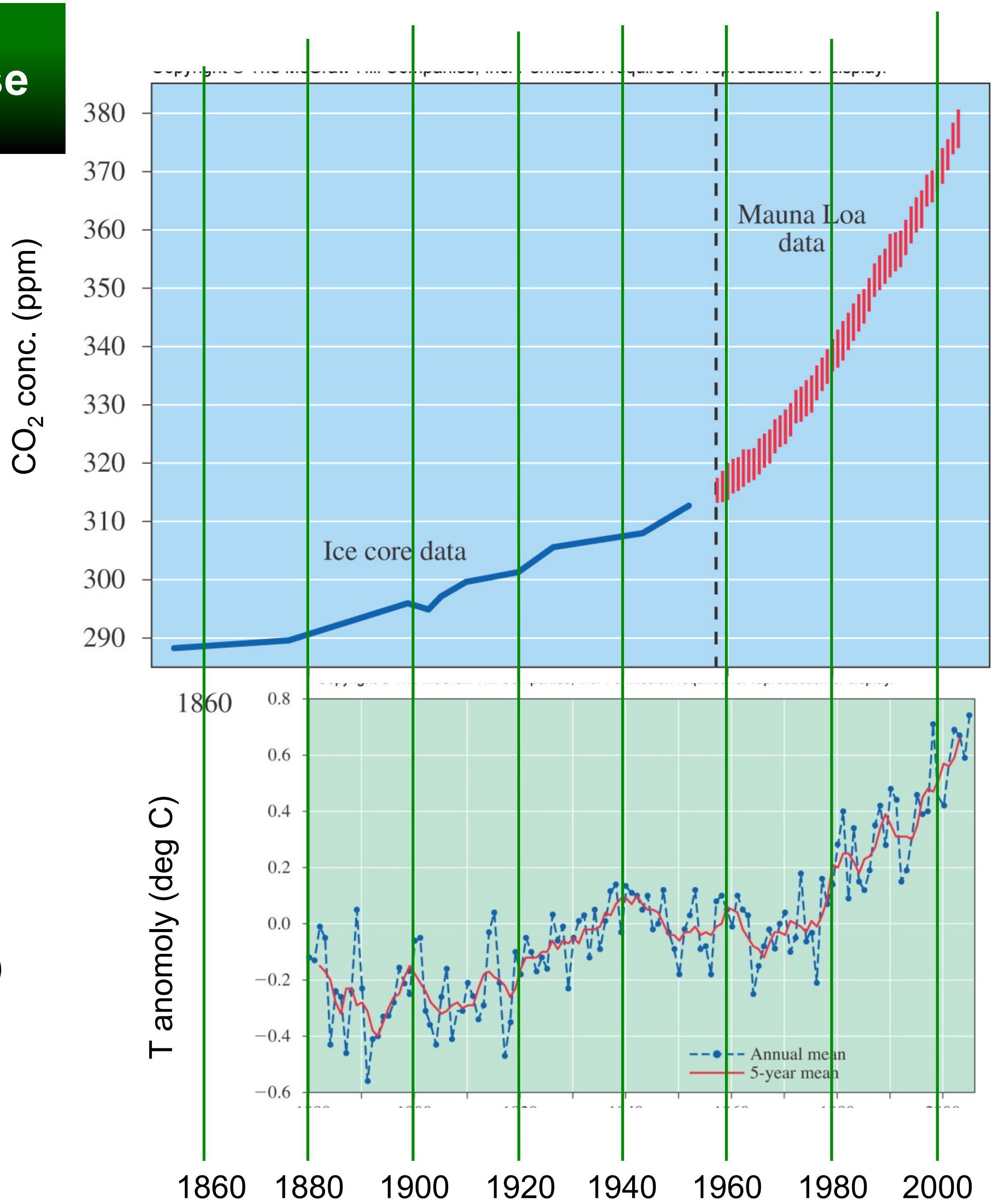
Correlation Between CO_2 Levels and Temperature

- How do we know about carbon dioxide and temperature in the past? Enter Antarctica…
- CO_2
  - **directly** measured in gas bubbles trapped in ice
- Temperature
  - **indirectly** measured by looking at ^2H:^1H ratios in the ice: water that contains ^2H isotopes condenses more readily than water with ^1H
  - the ^2H:^1H ratio depends on temperature (beyond the scope of this course at this time)
- The CO_2 and T data appear to be **correlated**

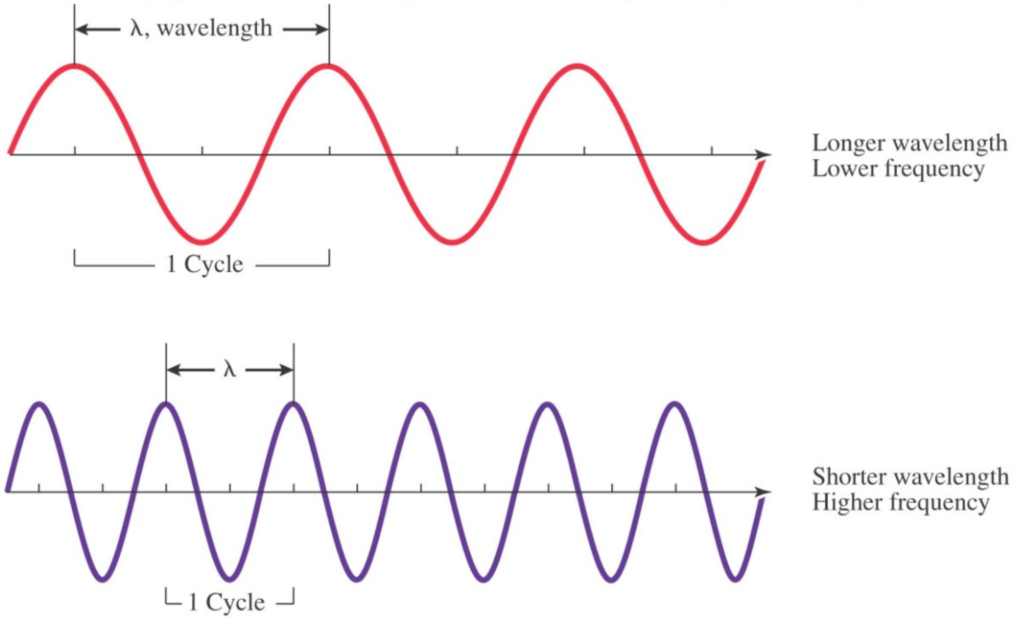


[CO_2] and *T*: Present Tense

- **Greenhouse effect**—absorption of heat radiation by atmospheric gases
  - 80% of the energy absorbed and then re-emitted by the Earth is gobbled up by the atmosphere
  - represents a steady state condition
- **Enhanced greenhouse effect**—absorption of heat beyond the 80%
- We are currently involved in an interesting and unprecedented (for humans) experiment: how will the Earth respond to [CO_2] > 380 ppm?

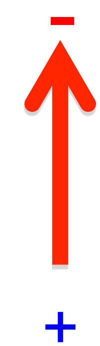


Light Absorption Requirements



For a substance to absorb light, there must be a change in dipole that occurs for that substance.

Thus, for a molecule to absorb IR radiation, there must be a change in the center of mass of the molecule—shape matters



Atmospheric gases: N_2 and O_2 don't absorb IR light, but CO_2 and H_2O do…

N_2 and O_2 are *not* greenhouse gases, but CO_2 and H_2O are…

Table 1.2 Typical Composition of Inhaled and Exhaled Air

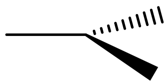
Substance	Inhaled Air (%)	Exhaled Air (%)
Nitrogen	78.0	75.0
Oxygen	21.0	16.0
Argon	0.9	0.9
Carbon dioxide	0.04	4.0
Water vapor	0.0	4.0

Determining Molecular Shapes Using Steric Numbers

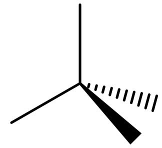
- Basic procedure:
  - 1. Determine # outer/valence electrons for each atom (Unit 3.2)
  - 2. Arrange outer/valence electrons so each atom has noble gas configuration (Unit 3.2)
  - 3. Electrons repel (but are attracted to protons) so want to be as far apart as possible—think 3-dimensionally

- 3D structure drawing:
  - if *steric number* (SN) = 2 (2 pairs or bonds): think **linear**
  - if SN = 3 (3 pairs or bonds): think **trigonal planar**
  - if SN = 4 (4 pairs or bonds): think **tetrahedral**
  - if SN = 5 (5 pairs or bonds): think **trigonal bipyramidal**
  - if SN = 6 (6 pairs or bonds): think **octahedral**

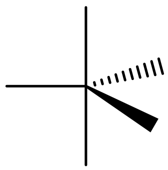
- Remember that (when asked on an exam) the molecule's **shape** depends *only* on the positions of atoms, not (lone pair) electrons



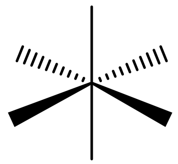
SN = 3



SN = 4



SN = 5

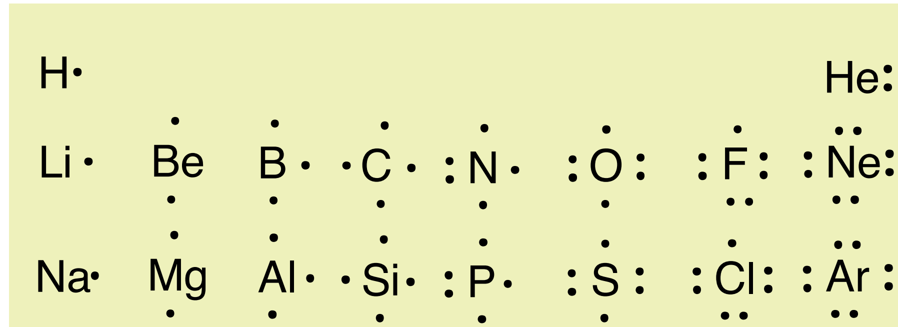


SN = 6

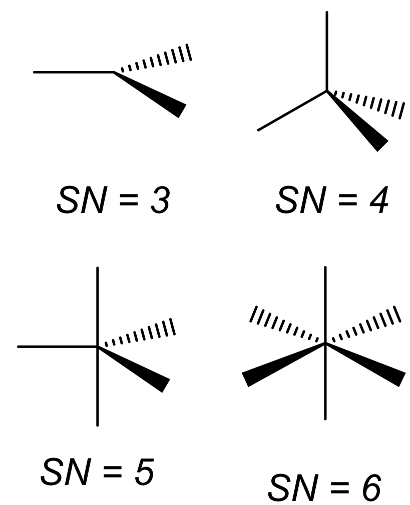
Practice Drawing Molecules

Examples to try:

1. O_3 (ozone)
2. CF_2Cl_2 freon 12 (CFC-12)
3. CO_3^{2-} (carbonate)
4. CH_3SH (methane thiol)
5. C_2H_4 (ethylene)
6. C_2H_6O (ethanol or dimethyl ether)
7. NO_3^- (nitrate)
8. SF_6 (sulfur hexafluoride)

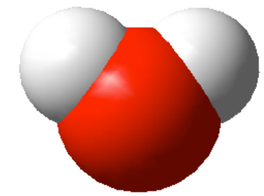


- Basic procedure:
  - 1. Determine # outer/valence electrons for each atom (Unit 3.2)
  - 2. Arrange outer/valence electrons so each atom has noble gas configuration (Unit 3.2)
  - 3. Electrons repel (but are attracted to protons) so want to be as far apart as possible—think 3-D
- The molecule's **shape** depends *only* on the positions of atoms, not (lone pair) e^-



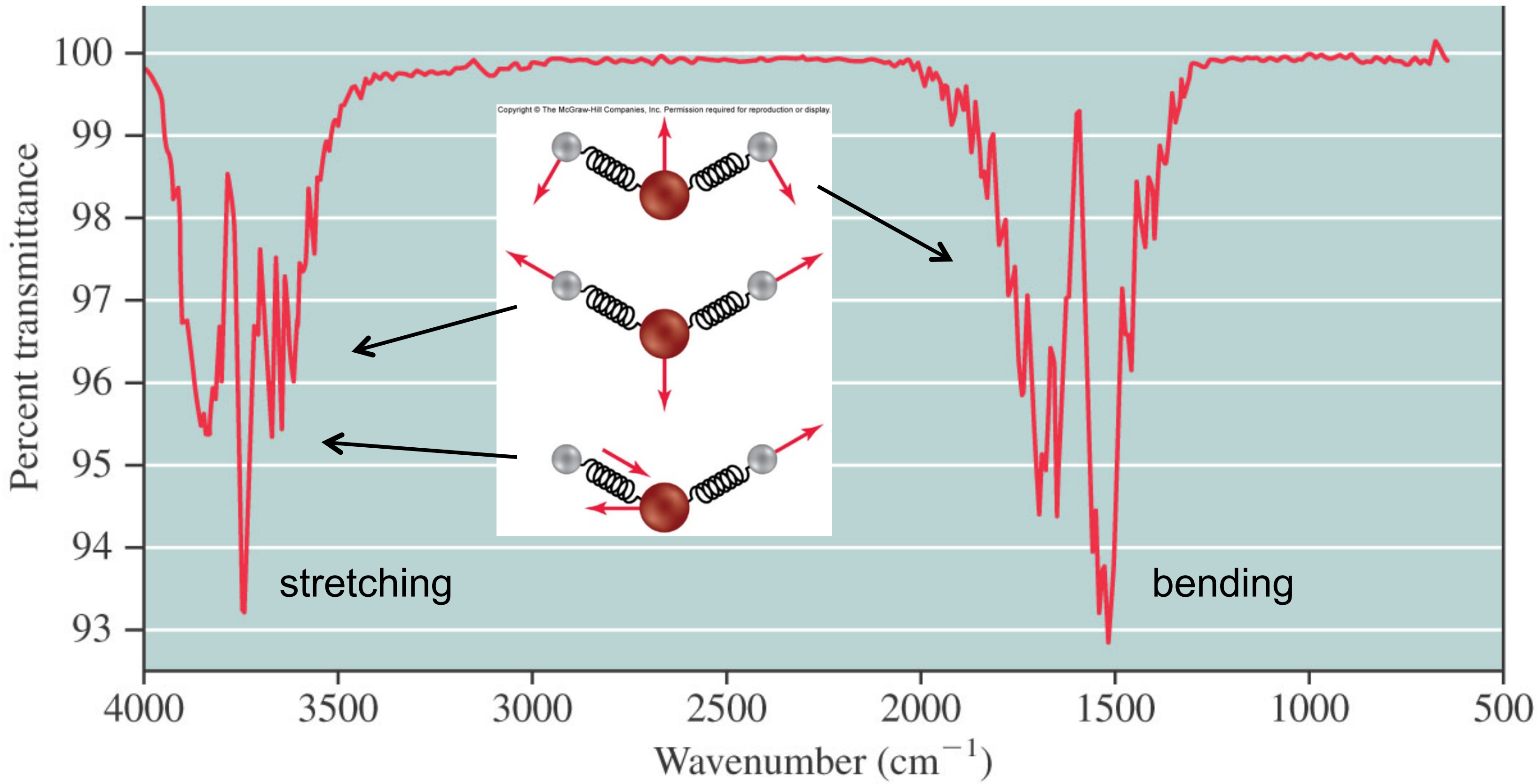
Vibrational Modes and IR Spectrum for Water

Infrared spectroscopy: shine IR light (heat) onto a substance, record what energies of light are absorbed (transmittance decreases when light is absorbed)

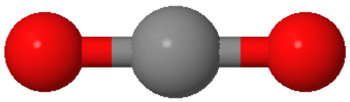


link to water vibrations!

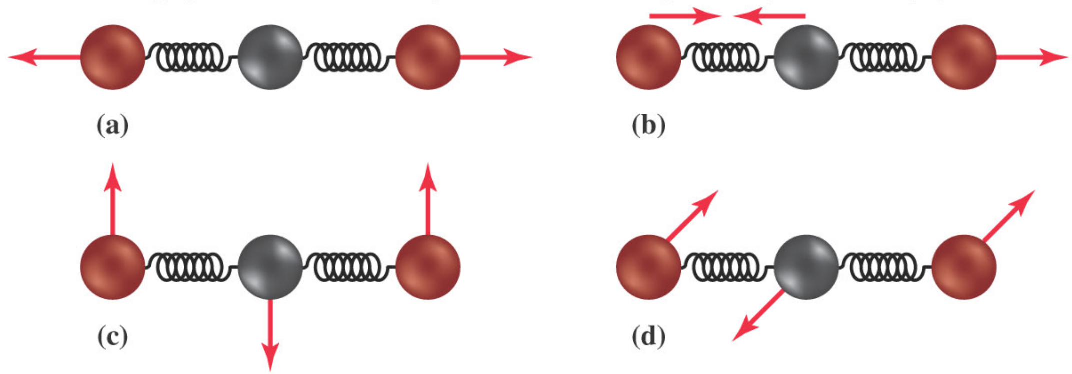
note: wavenumber (cm^{-1}) = 10,000,000 / λ (nm)



Vibrational Modes for Carbon Dioxide and Infrared Spectrum



link to CO_2 vibrations!

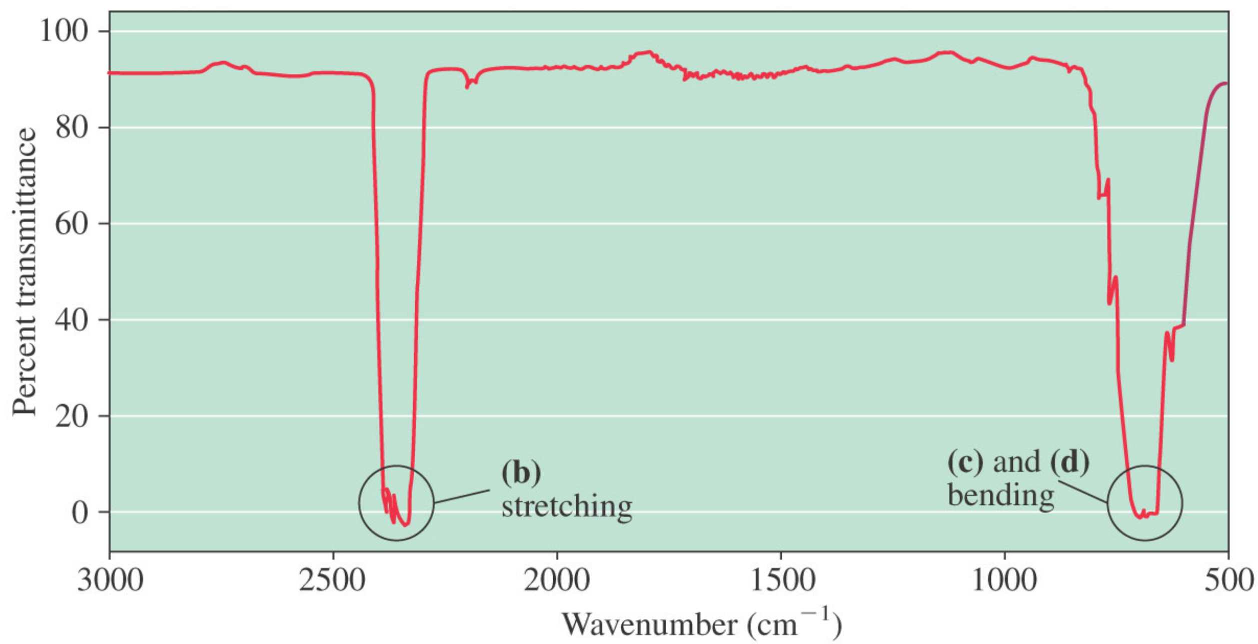


a & b: stretching modes

c & d: bending modes

Which of these vibrational modes can be turned on by the absorption of IR photons?

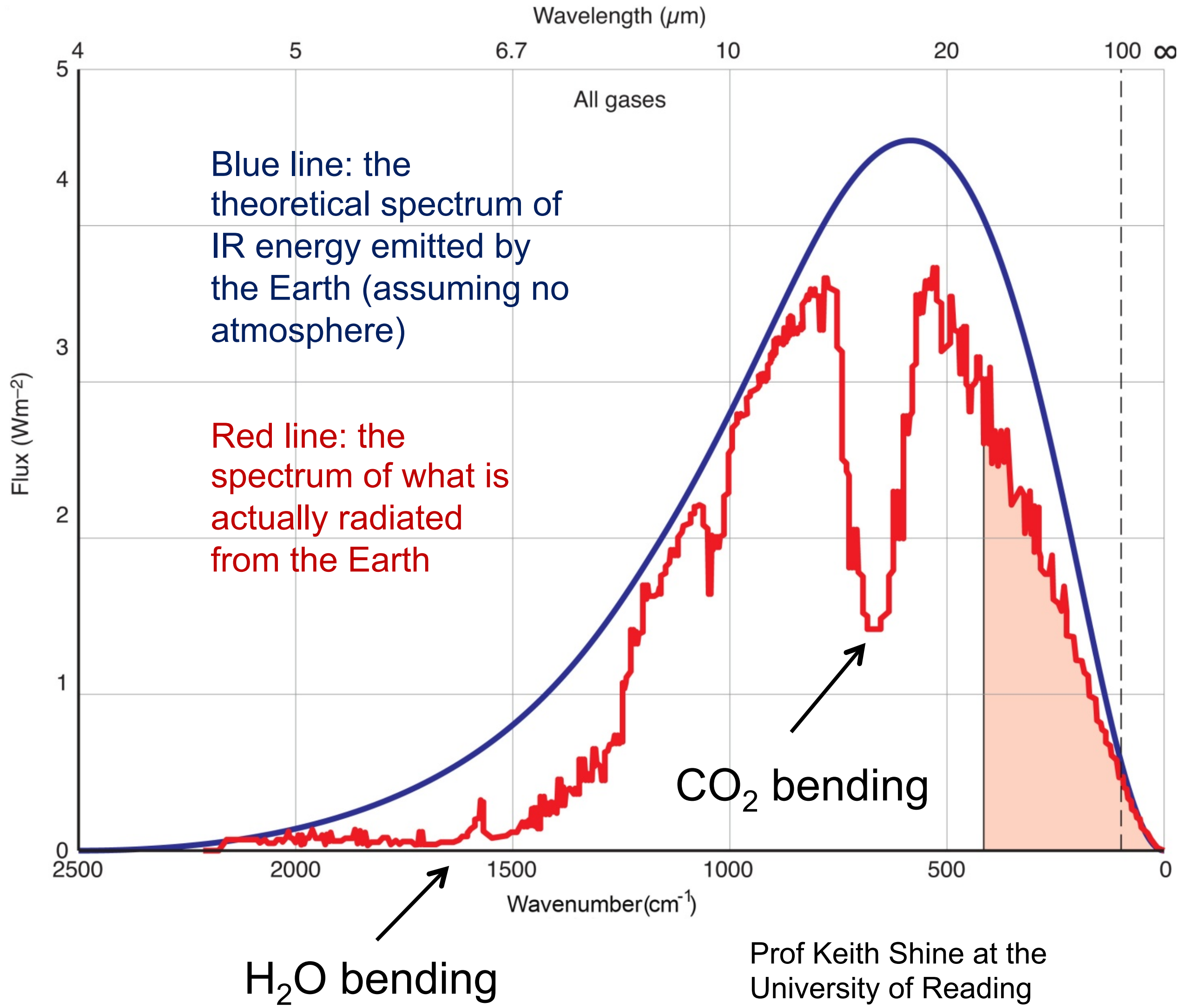
(need change in center of mass of molecule)



Why is CO_2 Important for Global Warming?

It's difficult to imagine a molecule better suited to soaking up the IR photons radiating from the Earth than carbon dioxide:

Note 900-1250 cm^{-1} range: most of this radiation escapes into space—if a gas absorbs in this range it has greater global warming potential…



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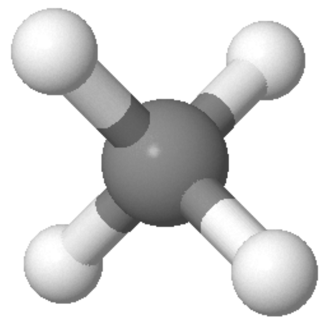
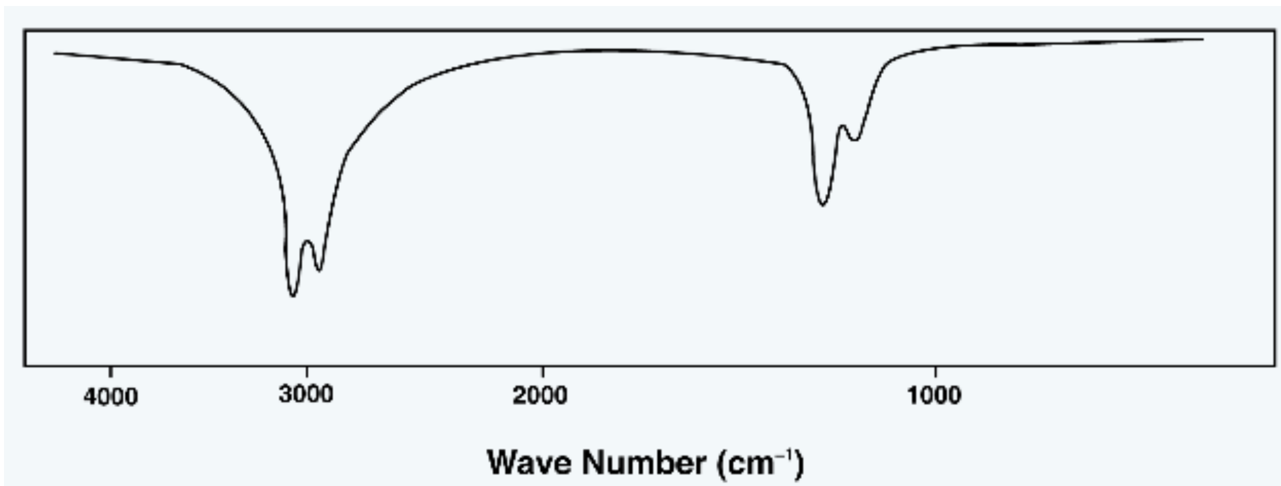
Methane

Is methane a greenhouse gas? If so, it needs to show vibrations that change its center of mass…

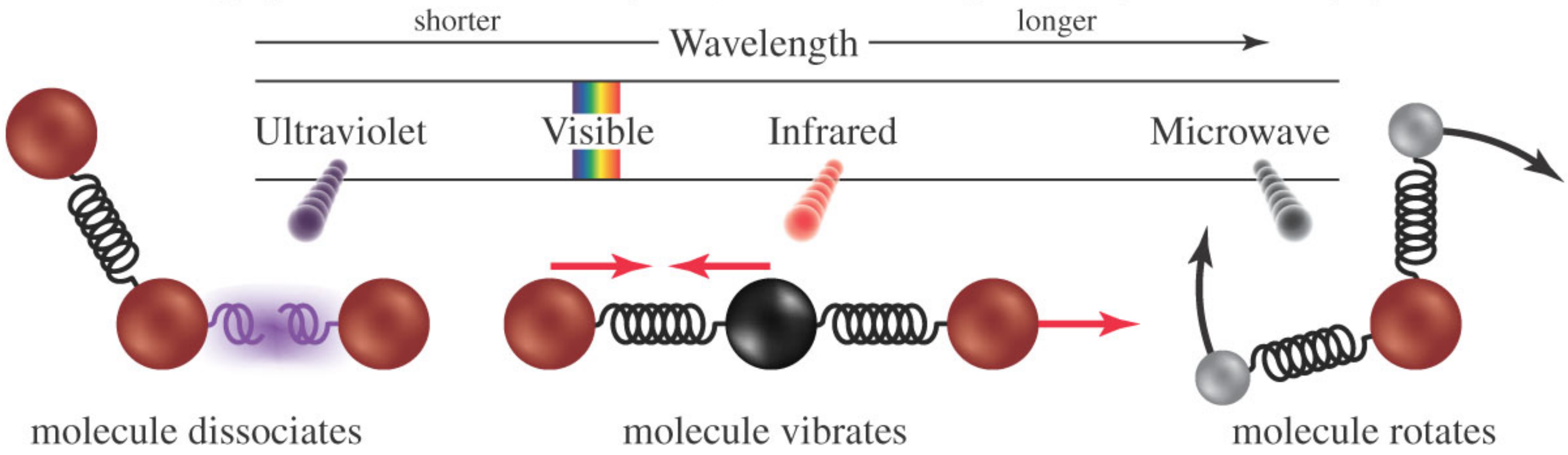
Click on molecule to link to CH_4 vibrations!





Also, the fact that there are absorptions of IR energy (the lowered transmittances at ~1200 and 3000 cm^{-1}) indicate that methane can absorb IR radiation and act as a greenhouse gas.

Review of How Light Interacts with Matter



Visible—depending on the energy and substance of interest, sometimes it breaks bonds, sometimes not; vibrations almost always accompany the excitation; in some cases visible light is re-emitted by the excited substance (fluorescence and phosphorescence)