Last Time

• The sum of all bond dipole vectors in a molecule is the molecular dipole moment.

• When a molecule absorbs an amount of energy and vibrates, it has gone from its ground state to a vibrational excited state.

• Vibrational Energy Levels are Quantized.

• Vibrational modes in which the dipole moment is altered are heat absorbing. These are most important for climate
Carbon Cycle

The series of processes by which carbon compounds are interconverted in the environment.
Reservoirs, Fluxes, and Resident Time

• Reservoirs are pools of carbon that can be uniquely defined.

• The rate of movement of carbon from one reservoir to another is the Flux.

• Resident Time: The average time that carbon spends in a given reservoir.
### Fluxes
(In Billions of Metric Tons per Year)

- **Land Plants**
  - Photosynthesis: 120
  - Plant respiration: 60
  - Soil respiration: 60
  - Plants to soils: 60
  - Fossil fuel formation: 0.0001
  - Fossil fuel burning: 6
  - Deforestation: 2
Fluxes
(In Billions of Metric Tons per Year)

• Oceans
  - Dissolving from atmosphere 107
  - Exsolving to atmosphere 105
  - Carbonate formation 0.3
  - Weathering 0.6

• Volcanoes
  - Volcano activity 0.1
Seasonal vs. Annual

• Large fluxes are seasonal
• Land: photosynthesis and respiration (~120 bMT/yr each way).
• Ocean: dissolving and exsolving (~110 bMT/yr each way)
• Over a year period most of the time these are in balance.
• Slightly out of balance now due to fossil fuel inputs

The big fluxes on a year-to-year basis are due to fossil fuel burning and deforestation.
Observations

• Flux of carbon OUT OF fossil fuel is 60,000 times faster than the flux of carbon INTO fossil fuels.
## Reservoirs

<table>
<thead>
<tr>
<th>Reservoir</th>
<th>Billions of Metric Tons</th>
</tr>
</thead>
<tbody>
<tr>
<td>Atmosphere</td>
<td>720 bMT</td>
</tr>
<tr>
<td>Ocean</td>
<td>39,000 bMT</td>
</tr>
<tr>
<td>Carbonates</td>
<td>100,000,000 bMT</td>
</tr>
<tr>
<td>Fossil fuels</td>
<td>4,000 bMT</td>
</tr>
<tr>
<td>Land plants</td>
<td>560 bMT</td>
</tr>
<tr>
<td>Soils</td>
<td>1500 bMT</td>
</tr>
</tbody>
</table>
Observations

• Flux of carbon OUT OF fossil fuel is 60,000 times faster than the flux of carbon INTO fossil fuels.
• Most carbon is in rocks such as carbonates and other sediments.
• Most of the carbon that is not in rocks is in the ocean.
• There is about 3 times more carbon in soils than in land plants.
Resident Times

- Land Plants: ~ 5 yr
- Atmosphere: ~ 3 yr
- Soils: ~ 25 yr
- Fossil fuels: ~ 650 yr
- Oceans: ~ 350 yr
- Carbonates: ~ 150 Myr
Observations on Resident Times

• Because some in/out fluxes are not balanced (e.g. atmosphere and fossil fuels) the resident times will be different. For the same reason reservoirs will grow or shrink.

• Our atmosphere mixes in about one year so the normal resident time of carbon in the air is long enough that is well mixed

  - Our $CO_2$ is everyone's problem and vice-versa.
Observations on Resident Times

Reservoirs are interconnected

➢ Short resident times are underestimates.

➢ Cleaning up $CO_2$ directly from the atmosphere:

✓ Reservoirs with longer resident time (e.g. the ocean) will put carbon back into the atmosphere.

Taking all observations into account, the atmospheric resident time is closer to 100 years!