Today’s goals...
- Composition of the current atmosphere
- How did the atmosphere get this way?

Questions to Think About
- Where did the earth’s atmosphere come from?
- Has the Earth’s atmosphere always been the same?
- Is there evidence that life has affected the composition of the atmosphere?
- Can we expect the makeup of the atmosphere to change in our lifetimes?

Present Atmospheric Composition

<table>
<thead>
<tr>
<th>Permanent Gases</th>
<th>Variable Gases</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Gas</strong></td>
<td><strong>Symbol</strong></td>
</tr>
<tr>
<td>Nitrogen</td>
<td>N₂</td>
</tr>
<tr>
<td>Oxygen</td>
<td>O₂</td>
</tr>
<tr>
<td>Argon</td>
<td>Ar</td>
</tr>
<tr>
<td>Neon</td>
<td>Ne</td>
</tr>
<tr>
<td>Helium</td>
<td>He</td>
</tr>
<tr>
<td>Hydrogen</td>
<td>H₂</td>
</tr>
<tr>
<td>Krypton</td>
<td>Kr</td>
</tr>
</tbody>
</table>

If the numbers do not change with time, what does this mean???

What are the major sources and sinks for:
- Oxygen?
- Water vapor?
- Carbon dioxide?
- Methane
- CFCs
- Ozone
- Nitrogen (trick question)

Paleo Carbon Cycling

Over the past 420,000 years atmospheric CO₂ has varied between 180 and 280 parts per million, beating in time with the last four glacial cycles.

Over the last millennium, CO₂ was very steady until the Industrial Revolution, when it began to rise rapidly

The atmospheric mixing ratio of CO₂ is expected to reach 700 to 900 ppm by 2100
- Last time CO$_2$ was this high was > 20 M yrs ago
- 10 to 20x higher hundreds of M yr ago
- Early atmosphere was mostly CO$_2$

"Reduced" carbon
- A very powerful "greenhouse gas"
- CH$_4$ has more than doubled since 1800!
- Sources:
  - Natural gas leaks
  - Biomass burning (fires)
  - Anaerobic decomposition (rice paddies, wetlands, cattle guts)
- Sink:
  - Oxidation in atmosphere
  - Growth rate has slowed dramatically since 1990, but we don’t really know why!

Ozone:
Why is it good for us?
Why is it bad for us?
How is it formed?
How is it destroyed?

First atmosphere consisted primarily of H and He (most abundant elements in the universe)
- Early Earth was continuously bombarded by high-energy collisions with other bodies
- H & He are very light (MW 1 and 4), easily lost when accelerated past terminal velocity
- Secondary atmosphere was formed primarily through volcanic emissions

Mt. St. Helens
adding to our atmosphere’s composition in 1980

A more continuous addition of gases and solids to our earth-atmosphere system on the big island of Hawaii
**How did the new atmosphere evolve?**

1) Volcanic emissions
   - Water vapor 85%
   - Carbon dioxide 10%
   - Nitrogen 1 - 5%
   - Sulfur 1 - 5%
   - Particles and surface materials

2) When collisions became less frequent, planet cooled

3) Water vapor condensed, forming oceans

5) Strong acids (HCl, HNO₃, H₂SO₄) dissolved readily into the oceans, taken out of atmosphere, combined with dissolved materials from continental weathering to make sea salt

6) Carbon dioxide dissolved incompletely in the oceans
   \[ H_2O + CO_2 \rightarrow H^+ + HCO_3^- \rightarrow 2H^+ + CO_3^{2-} \]

7) Dissolved carbonate (CO₃²⁻) in oceans combined with dissolved Ca from continents to form limestone (CaCO₃)

8) There's enough carbon in limestone rock today to make 100 atmospheres of pure CO₂

**Photosynthesis, Decomposition, and O₂**

- Marine photosynthesis evolved at least 2.3 billion years ago (half the age of the Earth)
- Releases free O₂
- When living things die, organic matter is decomposed (oxidized) back to CO₂
- No net change in CO₂ or O₂ if this happens!
- Slow, steady burial of reduced organic material led to steady increase of O₂
- CO₂ was steadily drawn down by both limestone formation and organic burial to trace amounts
- O₂ levels increased dramatically around 2.25 billion years ago, allowed ozone layer and land plants
- N₂ is pretty unreactive ... gets left behind. This is why current atmosphere is mostly N₂

**Requirements for photosynthesis**

- Life forms
  - First bacteria, later plants
- Sunlight
- Shielding from lethal ultraviolet radiation
- Limited by
  - AREAL DISTRIBUTION OF O₂ PRODUCERS
  - INITIALLY DETERMINED BY SHIELDING FROM UV RADIATION
  - EFFICIENCY OF ORGANISMS IN THEIR PRODUCTION OF O₂

**Photochemical Production of Ozone**

\[ 3O_2 + \text{ultra violet radiation} \rightarrow 2O_3 \]