Next quiz: Monday, May 13, 10-20 questions from the list below, plus questions from the lectures

Chapter 19: 1, 6, 7, 8, 10, 11, 15, 16, 29, 20, 21, 27, 42, 46
Chapter 20: 1, 2, 7, 13, 14, 16, 19, 20, 34, 37, 40, 41, 42, 43, 47, 48
Chapter 21: 1, 2, 3, 7, 10, 12, 13, 14, 16, 19, 20, 21, 27, 29, 30, 32, 34, 38, 39, 44, 45, 46
Chapter 22: 1, 3, 4, 6, 9, 10, 11, 12, 13, 16, 18, 24, 25, 27, 28, 31, 32, 34, 36, 39, 48
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 forms have affected the composition of the atmosphere?
• Can we expect 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>N&lt;sub&gt;2&lt;/sub&gt;</td>
</tr>
<tr>
<td>Oxygen</td>
<td>O&lt;sub&gt;2&lt;/sub&gt;</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>H&lt;sub&gt;2&lt;/sub&gt;</td>
</tr>
<tr>
<td>Xenon</td>
<td>Xe</td>
</tr>
</tbody>
</table>

*For CO<sub>2</sub>, 374 parts per million means that out of every million air molecules, 374 are CO<sub>2</sub> molecules.

†Stratospheric values at altitudes between 11 km and 50 km are about 5 to 12 ppm.

**Why are some Permanent and others are Variable?**
The Hole in the Ozone Layer!
It appears in the winter
Where did the present atmosphere come from?

Or,

why is there air?
Atmospheric Formation

Hypothesis: Captured from Solar Nebula
- Mostly Hydrogen and Helium
- Would have been quickly lost. Earth’s gravity is not great enough to either hold H or He at this temperature

If initially lost - where did the present atmosphere come from?

1. Hydrous minerals (water-bearing) outgassed from volcanoes
2. Brought to Earth by comets
Earth’s first atmosphere (H and He) was similar to that of Saturn’s moon: Titan
Secondary Atmosphere - Outgassing

Initially Composed of:
- Ammonia (NH$_3$)
- Hydrogen (H$_2$)
- Carbon dioxide (CO$_2$)
- Methane (CH$_4$)
- Water vapor (H$_2$O)
- Nitrogen (N$_2$)
- But NO OXYGEN!
The Faint Young Sun Paradox!
High carbon dioxide or methane solves the Faint Young Sun paradox due to the Greenhouse Effect.
No Significant Oxygen!

Evidence:

- No Rust Minerals
- Pyrite and Uraninite Conglomerates (these would rapidly oxidize today)

Witwatersrand conglomerate, South Africa (Middle Archean)
Atmospheric Evolution

**Primary** - Captured from Solar Nebula
- Mostly Hydrogen and Helium
- Quickly Lost

**Secondary** - Formed by Outgassing by Volcanoes

**Tertiary** - Modified by Life (addition of Oxygen)
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) planet cooled
3) Water vapor condensed, forming oceans
3) 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
4) Carbon dioxide dissolved incompletely in the oceans
   \[ H₂O + CO₂ \rightarrow H^+ + HCO₃^- \rightarrow 2H^+ + CO₃^{2-} \]
5) Dissolved carbonate (CO₃²⁻) in oceans combined with dissolved Ca from continents to form limestone (CaCO₃)
“Raining” of the Oceans
However, every once in a while...

Oceans were vaporized by large impacts
But eventually things settled down and we ended up with modern Oceans.
Photosynthesis and respiration

Oxic respiration ⇒

\[
\text{CH}_2\text{O} + \text{O}_2 \iff \text{CO}_2 + \text{H}_2\text{O}
\]

⇒ Photosynthesis

Gives off energy

Requires energy input
Where atmospheric **Oxygen** comes from

**photosynthesis**

\[ \text{CO}_2 + \text{H}_2\text{O} \Rightarrow \text{CH}_2\text{O} + \text{O}_2 \]

Carbon dioxide  Water  Carbohydrate  Oxygen
But it’s really part of the larger carbon cycle.

\[ \text{CO}_2 + \text{H}_2\text{O} \rightleftharpoons \text{CH}_2\text{O} + \text{O}_2 \]

*Photosynthesis* → Requires energy input

\( \lambda \) (light)

Chemical (oxidative) energy

Gives off energy

\[ \text{Respiration} \leftarrow \text{Gives off energy} \]
SeaWiFS Biosphere: 3 years
Radiation travels as waves or photons.

Waves do not require molecules to propagate.

Rate of energy loss is proportional to the 4th power of temperature.

### Electromagnetic Radiation

<table>
<thead>
<tr>
<th>TYPE OF RADIATION</th>
<th>RELATIVE WAVELENGTH</th>
<th>TYPICAL WAVELENGTH (meters)</th>
<th>ENERGY CARRIED PER WAVE OR PHOTON</th>
</tr>
</thead>
<tbody>
<tr>
<td>AM radio waves</td>
<td></td>
<td>100</td>
<td>Increasing</td>
</tr>
<tr>
<td>Television waves</td>
<td></td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Microwaves</td>
<td></td>
<td>$10^{-3}$</td>
<td></td>
</tr>
<tr>
<td>Infrared waves</td>
<td></td>
<td>$10^{-6}$</td>
<td></td>
</tr>
<tr>
<td>Visible light</td>
<td></td>
<td>$5 \times 10^{-7}$</td>
<td></td>
</tr>
<tr>
<td>Ultraviolet waves</td>
<td></td>
<td>$10^{-7}$</td>
<td></td>
</tr>
<tr>
<td>X rays</td>
<td></td>
<td>$10^{-9}$</td>
<td></td>
</tr>
</tbody>
</table>
Shortwave and Longwave Radiation

The hot sun radiates at shorter wavelengths that carry more energy.

Energy absorbed by the cooler earth is then re-radiated at longer wavelengths, as predicted by Wein's law.
Two Faces of Solar Energy

Ultra violet

Lethal

Visible

Energy source for life forms
Oxygen makes ozone which protects us from UV!

Photo-dissociation step 1

$$2 \text{H}_2\text{O} + \text{ultra violet radiation} \rightarrow 2 \text{H}_2 + \text{O}_2$$
In other words, Ozone protects us from deadly ultraviolet rays from the Sun!!!
Pressure

• Molecules bumping into an object create a force on that object
• Pressure is the force applied per unit area
  \[ P = \frac{\text{Force}}{\text{Area}}; \]
  where force is \( \text{mass} \times \text{gravity} \)

Which box below is exerting the greatest pressure upon the ground?
Pressure and Density of the Atmosphere

- Gravity holds most of the air close to the ground
- **The weight of the overlying air is the pressure** at any point
Vertical Structure

The world is a big place, but the atmosphere is very shallow. Consider ...

• In Billings, about 12% of the mass of the atmosphere is below our feet

• At the top of Beartooth (~11000 ft), you are above ~30% of the atmosphere’s mass

• You are closer to outer space than to Bozeman!
Temperature Scales

• In the US, we use **Fahrenheit** most often
• **Celsius** (centigrade) is a scale based on freezing/boiling of water
• **Kelvin** is the “absolute” temperature scale

<table>
<thead>
<tr>
<th>K</th>
<th>°C</th>
<th>°F</th>
</tr>
</thead>
<tbody>
<tr>
<td>373</td>
<td>100</td>
<td>212</td>
</tr>
<tr>
<td>363</td>
<td>90</td>
<td>194</td>
</tr>
<tr>
<td>353</td>
<td>80</td>
<td>176</td>
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<tr>
<td>343</td>
<td>70</td>
<td>158</td>
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<td>333</td>
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<td>140</td>
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<td>323</td>
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<td>313</td>
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<td>303</td>
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<td>86</td>
</tr>
<tr>
<td>293</td>
<td>20</td>
<td>68</td>
</tr>
<tr>
<td>283</td>
<td>10</td>
<td>50</td>
</tr>
<tr>
<td>273</td>
<td>0</td>
<td>32</td>
</tr>
</tbody>
</table>

- Boiling point of water at sea level

- 58°C (136°F) Highest temperature recorded in the world. El Azizia, Libya, September, 1922
- Average body temperature 37°C (98.6°F)
- Average room temperature
- Freezing (melting) point of water (ice) at sea level
- A bitter cold day

-89°C (−129°F) Lowest temperature recorded in the world. Vostok, Antarctica, July, 1983
Helium-filled weather balloons are released from over 1000 locations around the world every 12 hours (some places more often).

These document temperature, pressure, humidity, and winds aloft.
The atmosphere is **layered** according to its temperature structure.

In some layers the temperature **increases** with height.

In others it **decreases** with height or is **constant**.

Why?

... “pause” is a level

... “sphere” is a layer
Vertical Thermal Structure

- Heated in thermosphere by $O_2$ and $N_2$ absorption
- Heated in stratosphere by ozone absorption
- Heated from below by latent and sensible heat fluxes
Lower in the Atmosphere

We live here
Heat transfer processes

• **Conduction** - Where molecules transfer energy by coming into contact with one another.

• **Convection** - Where a fluid moves from one place to another, carrying it’s heat energy with it.
  – In atmospheric science, convection is usually associated with vertical movement of the fluid (air or water).
  – Advection is the horizontal component of the classical meaning of convection.

• **Radiation** - The transfer of heat by radiation does not require contact between the bodies exchanging heat, nor does it require a fluid between them.
Conduction – Direct Heat Transfer

Conduction of heat energy occurs as warmer molecules transmit vibration, and hence heat, to adjacent cooler molecules.

Warm ground surfaces heat overlying air by conduction.
Radiation – heat transferred even in a vacuum!
Heat driven convection

1. Bottom water is warmed
2. It expands and is therefore less dense
3. It rises to the surface and then spreads out
4. Cooler water at the sides descends to fill the void
Stellar modeling

- Convection zone
- Core
- Radiation zone
Moist Convection

A daily occurrence in summer along the high plains --
caused by surface heating, rising buoyant plumes, and
the release of latent heat in clouds
A convective thunderstorm
'convective' tornadoes
Hurricanes
Convection in a hurricane
Temperature, Density, and Convection

Heating of the Earth’s surface during daytime causes the air to mix
Solar radiation passes first through the upper atmosphere, but only after absorption by earth's surface does it generate sensible heat to warm the ground and generate longwave energy. This heat and energy at the surface then warms the atmosphere from below.
Water's unique molecular structure and hydrogen bonds enable all 3 phases to exist in earth's atmosphere.
Water's unique molecular structure and hydrogen bonds enable all 3 phases to exist in earth's atmosphere.
Energy associated with phase change

- **Solid**
  - Add 80 calories
  - Melting
  - Add 100 calories
  - Warming
  - Add 540 calories
  - Evaporating
  - Gas
  - Water vapor

- **Liquid**
  - Water

- **Gas**
  - Condensing
  - Remove 540 calories

Latent heat of fusion — 80 calories
Latent heat of vaporization — 540 calories

80 calories  100 calories  540 calories!