The Aerosol World

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Our atmosphere
- Earth atmosphere is uniquely different from atmospheres on other planets

Importance of atmosphere
- Is a key part of biosphere
- Controls the climate
- Filters out harmful UV radiation and cosmic particles

Humans and atmosphere
- Humans steadily and detrimentally alter the atmospheric composition
Earth Atmosphere Today

- It is strongly oxidizing (21% oxygen)
- It has distinct temperature layers
- There is an exponential pressure decrease with elevation. 99.9% mass contained below the stratopause (50 km) ⇒ atmosphere is very thin! Compare this to the Earth diameter of 12,742 km.
- Mass of atmosphere is tiny relative to the Earth mass but large relative to the mass of all humans
  - Earth mass = $5.97 \times 10^{24}$ kg
  - Atmospheric mass = $5.14 \times 10^{18}$ kg
  - Mass of humans $\sim 5 \times 10^{11}$ kg

**Table 1-1 Mixing Ratios of Gases in Dry Air**

<table>
<thead>
<tr>
<th>Gas</th>
<th>Mixing ratio (mol/mol)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nitrogen ($N_2$)</td>
<td>0.78</td>
</tr>
<tr>
<td>Oxygen ($O_2$)</td>
<td>0.21</td>
</tr>
<tr>
<td>Argon (Ar)</td>
<td>0.0093</td>
</tr>
<tr>
<td>Carbon dioxide ($CO_2$)</td>
<td>$365 \times 10^{-6}$</td>
</tr>
<tr>
<td>Neon (Ne)</td>
<td>$18 \times 10^{-6}$</td>
</tr>
<tr>
<td>Ozone ($O_3$)</td>
<td>$(0.01-10) \times 10^{-6}$</td>
</tr>
<tr>
<td>Helium (He)</td>
<td>$5.2 \times 10^{-6}$</td>
</tr>
<tr>
<td>Methane (CH$_4$)</td>
<td>$1.7 \times 10^{-6}$</td>
</tr>
<tr>
<td>Krypton (Kr)</td>
<td>$1.1 \times 10^{-6}$</td>
</tr>
<tr>
<td>Hydrogen (H$_2$)</td>
<td>$500 \times 10^{-9}$</td>
</tr>
<tr>
<td>Nitrous oxide ($N_2O$)</td>
<td>$310 \times 10^{-9}$</td>
</tr>
</tbody>
</table>

**FIGURE 1.1** Typical variation of temperature with altitude at mid-latitudes as a basis for the divisions of the atmosphere into various regions. Also shown is the variation of total pressure (in Torr) with altitude (top scale, base 10 logarithms) where 1 standard atmosphere $= 760$ Torr.
Earth Atmosphere is “Flat”!

For most practical purposes, lower atmosphere can be regarded as flat. Earth curvature only needs to be considered in very special cases.

Drawn to scale
Earth’s Atmosphere in Perspective

How about other planets?

- All major planets except Pluto and Mercury, and some large moons (Titan, the largest moon of Saturn) have atmospheres.
- Properties of atmospheres on neighboring Mars, Venus, and Earth are amazingly different!
- Earth is unique in:
  - Very high $O_2$ content (close to spontaneous combustion limit)
  - High $H_2O$ content
  - Existence of life

### Comparison between Venus, Mars, and the Earth

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Venus</th>
<th>Earth</th>
<th>Mars</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total mass ($10^{27}$ g)</td>
<td>5</td>
<td>6</td>
<td>0.6</td>
</tr>
<tr>
<td>Radius (km)</td>
<td>6049</td>
<td>6371</td>
<td>3390</td>
</tr>
<tr>
<td>Atmospheric mass (ratio)</td>
<td>100</td>
<td>1</td>
<td>0.06</td>
</tr>
<tr>
<td>Distance from Sun ($10^6$ km)</td>
<td>108</td>
<td>150</td>
<td>228</td>
</tr>
<tr>
<td>Solar constant ($W m^{-2})^a$</td>
<td>2613</td>
<td>1367</td>
<td>589</td>
</tr>
<tr>
<td>Albedo (%)</td>
<td>75</td>
<td>30</td>
<td>15</td>
</tr>
<tr>
<td>Cloud cover (%)</td>
<td>100</td>
<td>50</td>
<td>Variable</td>
</tr>
<tr>
<td>Effective radiative ($^oC$)</td>
<td>-39</td>
<td>-18</td>
<td>-56</td>
</tr>
</tbody>
</table>

**temperature**

- Surface temperature ($^oC$): 427, 15, -53
- Greenhouse warming ($^oC$): 466, 33, 3
- $N_2$ (%): <2, 78, <2.5
- $O_2$ (%): <1 ppmv, 21, <0.25
- $CO_2$ (%): 98, 0.035, >96
- $H_2O$ (range %): $1 \times 10^{-4}$ – 0.3, $3 \times 10^{-4}$ – 4, <0.001
- $SO_2$ (fraction): 150 ppmv, <1 ppbv, Nil

Cloud composition: $H_2SO_4$, $H_2O$, Dust, $H_2O$, $CO_2$

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*The intensity of the solar radiation over a square meter of surface at a distance equal to that from the Sun to the planet’s orbit.*

From Graedel and Crutzen, 1995.

Atmospheric chemistry and Global Change, NCAR, 1999
Hot Topic in 2012: Mars Curiosity Rover

Images taken from:
http://marsprogram.jpl.nasa.gov/
Mars Curiosity Rover

http://msl-scicorner.jpl.nasa.gov/Instruments/
http://mars.jpl.nasa.gov/msl/

Cameras
- Mast Camera (Mastcam)
- Mars Hand Lens Imager (MAHLI)
- Mars Descent Imager (MARDI)

Spectrometers
- Alpha Particle X-Ray Spectrometer (APXS)
- Chemistry & Camera (ChemCam)
- Chemistry & Mineralogy X-Ray Diffraction/X-Ray Fluorescence Instrument (CheMin)
- Sample Analysis at Mars (SAM) Instrument Suite

Radiation Detectors
- Radiation Assessment Detector (RAD)
- Dynamic Albedo of Neutrons (DAN)

Environmental Sensors
- Rover Environmental Monitoring Station (REMS)

Atmospheric Sensors
- Mars Science Laboratory Entry Descent and Landing Instrument (MEDLI)
Variety of gases released from Rocknest samples

Major gases released on heating

Gases detected by SAM include water (a few percent), and lesser amounts of carbon dioxide, oxygen, and sulfur dioxide.

SAM experiment types
- Gas composition
- Isotopes in light elements
- Specific search for organics

No organics detected yet – the search is on-going

For three separate experiments
Red bar - sample temperature for gas sent to TLS
Blue bar – sample temperature for gas sent to GC
Atmospheric Evolution: The Imprint of Life

The evolution of Earth’s atmosphere is intricately tied to the evolution of life. Biological processes are responsible for many disequilibria in today’s atmosphere (e.g., high O$_2$ content). In the past, the atmosphere was not anywhere close to what it is now.

Figure 16.1. Probable evolution of the relative abundance (in percent) of chemical composition of the atmosphere during the Earth’s history (Allegre and Schneider, 1994).

Figure 16.2. Vertical distribution of major atmospheric constituents in a weakly reduced, prebiotic atmosphere. The major gases are N$_2$ and CO$_2$. Photochemical destruction of CO$_2$ leads to the production of O and O$_2$ in the upper atmosphere (Kasting, 1990).
Units in Atmospheric Sciences

- Temperature is usually measured in Kelvin
- Pressure has many different units
- Density, concentration, and mixing ratios

\[
\begin{align*}
\text{T[K]} &= \text{T[°C]} + 273.15 \\
\text{T[K]} &= \text{T[°F]} \times \frac{5}{9} + 255.37 \\
1\ \text{atm} &= 760\ \text{Torr} = 101325\ \text{Pa} \\
1013.25\ \text{hPa} &= 1.01325\ \text{bar} = 14.696\ \text{psi} \\
1\% &= 10^4\ \text{ppm} = 10^7\ \text{ppb}
\end{align*}
\]

Mixing ratio is very useful quantity. It shows how many molecules of a given kind there are relative to all the other molecules. Mixing ratio of stable gases does not change with altitude even though the total pressure drops exponentially.

Example: Each cubic centimeter of air at sea level contains approximately \(2.5 \times 10^{19}\) molecules. Most of these molecules are nitrogen (78.1% or 781 parts per thousand) and oxygen (21.0% or 210 parts per thousand). Clean atmosphere is known to contain 10 ppb of ozone (O\(_3\)). It means that each cubic centimeter of air at sea level contains approximately \(10 \times 10^{-9} \times 2.5 \times 10^{19} = 2.5 \times 10^{11}\) molecules of ozone.
Atmosphere is a Soup!

- In addition to stable gases like nitrogen, atmosphere contains thousands of trace molecules, some of which are rather toxic.
- Atmosphere is additionally spiced up by aerosol particles – tiny bits of liquid or solid material suspended in the air by Brownian motion.
- Representative trace molecules:
  - Carbon dioxide (CO$_2$) and other greenhouse gases (H$_2$O, N$_2$O, CH$_4$, ...)
  - Gasoline vapors and other hydrocarbons (C$_n$H$_m$)
  - Sulfur dioxide (SO$_2$) from fuel burning
  - Nitrogen oxides (NO and NO$_2$) from fuel burning
  - Ozone (O$_3$) produced in smog
  - Isoprene, pinene, and hundreds of other volatile chemicals emitted by plants (smells)
  - Pesticides, insecticides, toxins, molecules produced in cooking, etc.
- Representative particles:
  - Organic aerosols (produced in smog and over forests)
  - Soot (diesels)
  - Dust (natural and industrial)
  - Meteoritic debris
  - Sea-salt (over oceans and near coasts)
  - Cooking aerosols ("greaseballs")