Lecture 10:

The Air We Breathe: Earth's Atmosphere

Astronomy 141 – Winter 2012

In this lecture I will describe the properties of the Earth's atmosphere.

The present-day atmosphere is mostly Nitrogen (N_2) and Oxygen (O_2),

The atmosphere is divided vertically into thermal layers.

The Earth is too small to retain Hydrogen and Helium.

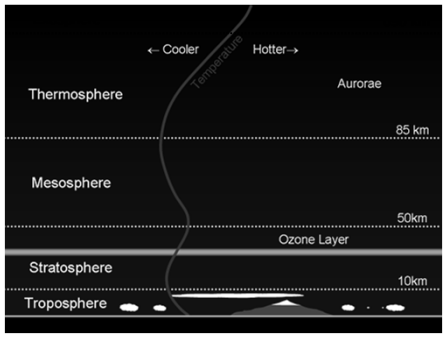
The Greenhouse Effect makes the Earth ~35°C warmer than it would be without an atmosphere.

The primordial (early) atmosphere was very different than it is today.

The Earth's Atmosphere in the present day is composed mostly Nitrogen and Oxygen.

- 78% N_2
- 21% O_2
- 1% H_2O (Water Vapor)
- 0.93% Argon
- CO_2 (0.038%)
- Traces of
  - CH_4 (methane),
  - Inert Gases (Ne, He, Kr, Xe)
- Particulates
  - silicate dust
  - sea salt
  - sulfates

The Earth's atmosphere is divided vertically into five *Thermal Layers*



Atmospheric Pressure drops by 50% for every 5.6km you go up in altitude.

At Sea Level: ~1 kg/sq-cm (14 pounds/sq-inch)

Air Pressure drops exponentially by ~50% for every 5.6 km of altitude gain.

5.6 km - 50%
~11km - 25%
…
56 km - 0.1%

Mt. Everest:

Altitude: 8850 m
Pressure: ~1/3 sea-level

The Earth's gravity is too low to retain Hydrogen and Helium in its atmosphere.

H & He are small and light, and so move very fast at a given atmospheric temperature.

The mean atomic speeds are *greater* than the escape velocity from the Earth.

Most of the H and He escaped long ago.

Heavier molecules (N_2, O_2, H_2O, CO_2, etc.) stay trapped in the atmosphere.

The ability of a planet to retain atmospheric gasses depends on its mass and temperature.

Massive planets have bigger escape speeds

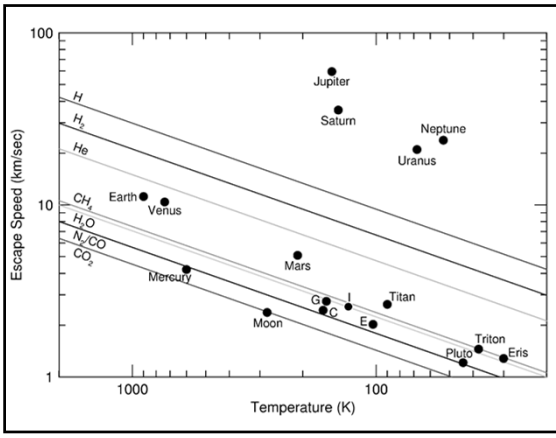
$$v_{esc} = \sqrt{\frac{2GM}{R}}$$

At higher temperatures, molecules move faster

$$v_{th} = \sqrt{\frac{3kT}{m}}$$

At a given Temperature, though, bigger molecules move *slower*

Massive planets can hold on to all gases better
Smaller planets must be colder to hold on to gases



Why is the Earth so warm?

If there was no atmosphere, the Earth's temperature would be a balance between

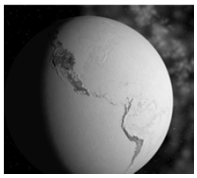
- Sunlight absorbed by the Earth (gain)
- Infrared photons radiated by the warm Earth (loss)

Estimated Equilibrium Temperature:

T=260 K

But, water freezes at 273 K

Why is the Earth not frozen?

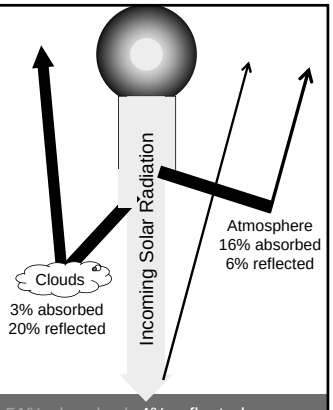


Where does all the sunlight go?

51% absorbed by the ground & oceans

19% absorbed by atmosphere

30% reflected back into space



Ground & Oceans: 51% absorbed, 4% reflected

The Greenhouse Effect makes the Earth about 35°C warmer than it would be if it had no atmosphere.

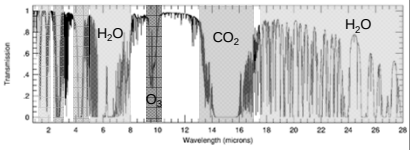
Visible Sunlight passes through the Earth's atmosphere and is absorbed by the ground

- Sunlight warms up the ground
- The warm ground radiates infrared photons

But, the atmosphere is *opaque* to most IR photons:

- Infrared photons are absorbed by molecules of H_2O, CO_2, CH_4 and others.

This absorbed energy heats the atmosphere



After losing most of its original gasses, the early atmosphere was built by outgassing from volcanoes

Volcanoes emit mostly H_2O and CO_2 plus H_2S, SO_2 and some CO but *no Oxygen*.

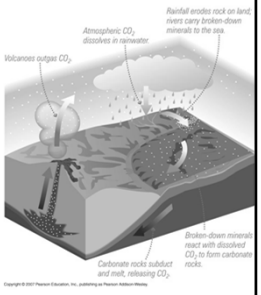
Water condensed as rain to build up the oceans.

What little oxygen was present was removed by mineral oxidation.

The primordial atmosphere had ~1000 times more Carbon Dioxide (CO_2) than it does now.

Where did it all go?

- H_2O rained out to form the oceans.
- CO_2 dissolved in rain & ocean water
- Precipitated out as carbonate rocks (limestone)
- N_2 stayed behind and became the dominant component.



Today most of the CO_2 is locked up in crustal rocks & dissolved in the oceans

Where did the Oxygen come from?

Molecular Oxygen (O_2) comes from life:

- Photosynthesis in plants and algae produced the first O_2 about 2.4 Gyr ago
- O_2 content increased rapidly from 1% to 21% during the last 600 Myr.

Ozone (O_3):

- Forms in the stratosphere when O_2 interacts with solar UV photons
- Blocks UV from reaching the ground.
- Made life on land possible.

O_2 & O_3 are signs of life (photosynthesis)

The Earth's atmosphere is a complex, dynamic system that has evolved over time.

Past Evolution:

- Condensation of H_2O into the oceans
- Locking up CO_2 into carbonaceous rocks
- Formation of O_2 by photosynthesis

This evolution continues into the present day:

- CO_2 is regulated by a complex cycle
- Increases in O_2 and CH_4 from "biomass"
- Human activity (fuel burning & agriculture)