Atmospheres of the Terrestrial Planets

I. Intro
   A. Compare 4 planets
   B. Definition of an Atmosphere
      1. The layer of gaseous material surrounding a planet
      2. Example: Earth’s atmosphere is predominantly $N_2$ and $O_2$ at the bottom but at 500km in height it is mostly $O$ and $H$
      3. Densities fall off exponentially (straight line on Figure 4.6).
      4. What happens at the kink?
   C. How high does an atmosphere go?
      1. No clear end point since the density (number of atoms/m³ just keeps falling off ever more slowly as one gets further away.
      2. Eventually, one cannot distinguish between the atmosphere and the interplanetary medium.

II. Atmospheric Temperatures
   A. When we talk about temperature outside, we’re not usually concerned with the soil temperature. Instead, we’re talking about atmospheric temperature.
   B. We need some way of gauging how hot a planet’s atmosphere will be.
   C. The simplest approximation is to assume the following: (figure 10.3)
      1. Energy entering from the sun is determined by three dominant factors? Distance, size, and reflectivity.
      2. Distance from a star tells you the fraction of light which reaches the surface of a planet. The Earth receives about a 1500W/m².
3. The size just tells you how much of the planet is exposed to light.
   a. What does the Earth look like from the perspective of the sun?
   b. A disk of area $\pi R_E^2$ where $R_E = 6,800 km$
4. Reflectivity is controlled by the planets Albedo
   a. An albedo of 0 means completely absorbent
   b. An albedo of 1 means completely reflective
   c. What material has an albedo of almost 0? Chuck of coal
   d. What material has an albedo of almost 1? Mirror
   e. If a planet has an albedo of 1 what would you expect it’s temperature to be? Very cold - only internal heating.
5. In our solar system: Total power absorbed
   \[
   P_{in} = L_s \frac{1}{4\pi d_p^2} \times \pi R_p^2 \times (1 - \text{albedo})
   \]
   \[
   = 1,360 \text{ W/m}^2 \times \frac{1}{d_p^2} \times \pi R_p^2 \times (1 - \text{albedo})
   \]
6. $d_p$ is in units of AU from the sun
7. $R_p$ is in meters
D. Power output.
   1. How does a planet get rid of it’s heat?
   2. Shedding hot material (sun does this but planets only do it a little)
   3. Reradiating according to the Stephen Boltzmann law
      a. $P_{out} = \sigma T^4 \times 4\pi R_p^2$
      b. $\sigma = 5.7E - 8 \text{ W/m}^2/T^4$
E. Temperature is determined by the balance between Power in and out
   1. In a steady system $P_{in} = P_{out}$
   2. Combine two eq’n’s above:
      \[
      T = 280 \text{ } K \left( \frac{1 - \text{albedo}}{d_p^2} \right)^{1/4}
      \] (1)
3. If more power arrives then the temperature will climb.
4. But, as the temperature climbs, then more power will radiate back into space until $P_{in} = P_{out}$.

F. Other factors affect temperature? Planet rotation
   1. What will happen if a planet always keeps one face toward the sun or rotates very slowly like Mercury?
   2. What if it rotates very quickly? Uniform temperature.
   3. Most planets are intermediate cases. Complicated ...
   4. We'll usually make the uniform temperature assumption.

G. Compare real planets with blackbody temp.
H. The black body temp sets a minimum temp.

III. Green house effect
   A. Show Fig 10.4 - light interacts with molecules
   B. Coincidence: the dominant frequency of radiating bodies is infrared and some important gas molecules absorb these infrared photons
   C. Greenhouse gases: $CO_2$, $H_2O$, $CH_4$, $NH_3$
   D. Not Greenhouse gases: $N_2$, $O_2$
   E. What happens to a molecule when it absorbs an infrared photon?
      1. Get's hotter
      2. Some energy is reradiated in a random direction.
      3. So, a photon which came from the ground is scattered into another direction
      4. Net effect is the rate at which energy escapes the atmosphere slows
      5. Energy is trapped as infrared radiation and heat

IV. Chemistry also governs but this leads to complexity
   A. UV or X-ray radiation can also break molecules apart leading to photo-chemistry
   B. Example: in the Earth's atmosphere ozone, $O_3$ plus UV gives $O_2$ absorbing energy in the part of the atmosphere called the stratosphere
V. Generic Complex atmosphere:
   A. Show figure 10.6
   B. How do you know this? Measurements
   C. How do you explain this?
      1. You make models where at every altitude you set power
         in = power out
      2. power can go in from solar radiation, motion of air, photo-
         chemical
      3. power out from radiation, motion of air, chemistry
      4. Find a solution at all altitudes simultaneously
      5. Not a simple process.
      6. Results give the kind of atmosphere measured below.
   D. Troposphere
      1. Green house gases trap infrared
      2. White light hits ground (some is reflected)
      3. Ground is hottest because that is where the light power
         becomes heat
      4. If the air had no greenhouse gases how would its temper-
         ature vary? Cool rapidly as you ascend - only conduction
         and convection to heat the air.
      5. Greenhouse gases give another, more efficient way to heat
         the air
      6. All the weather occurs in the troposphere
   E. Stratosphere
      1. Reach an area that absorbs energy
      2. Most planets don’t have a stratosphere - depends on the
         composition of the atmosphere
      3. In Earth stratosphere, UV + O₂ gives O₃ 40-60km.
      4. How will heat move in this region? Conduction and radi-
         ation - inefficient methods.
      5. No convection - little vertical motion of air
      6. Material get’s stuck in the lower stratosphere
      7. Upper stratosphere cools and convects
   F. Thermosphere and Ionosphere

4
1. X-ray absorbing regions
2. What happens to an atom hit by an X-ray - ionizes and becomes a plasma
3. At top of this region mostly plasma - 1000km on Earth
4. At bottom of this region mostly neutral and a little plasma - 80km on Earth
5. X-rays reach the bottom of the thermosphere because the density is so low and the odds of a photon encountering an electron at any point is quite low.

G. Exosphere
1. Region of atmosphere where density and, hence, collisions are so low, that gases fly off into the interplanetary medium regularly.
2. Temperature rises because the solarwind temperature is \(~20,000\)K and it has to match that.
3. Essentially all that Mercury and the moon have - a low density exosphere.

VI. Compare Mars, Earth and Venus - Fig 10.9

VII. Magnetosphere
A. The Earth’s atmosphere is subject to another effect.
B. The solar wind hits the Earth’s magnetic field and get’s directed around the Earth
C. Except where the field lines direct particles into the Poles
D. Lead to some bizarre behavior. - show pictures.