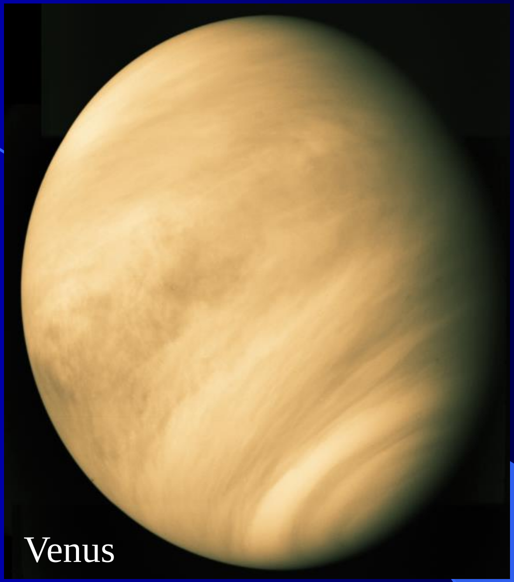
# The Terrestrial Planets, Life Cycle, and Atmosphere

Mercury



Venus

Earth

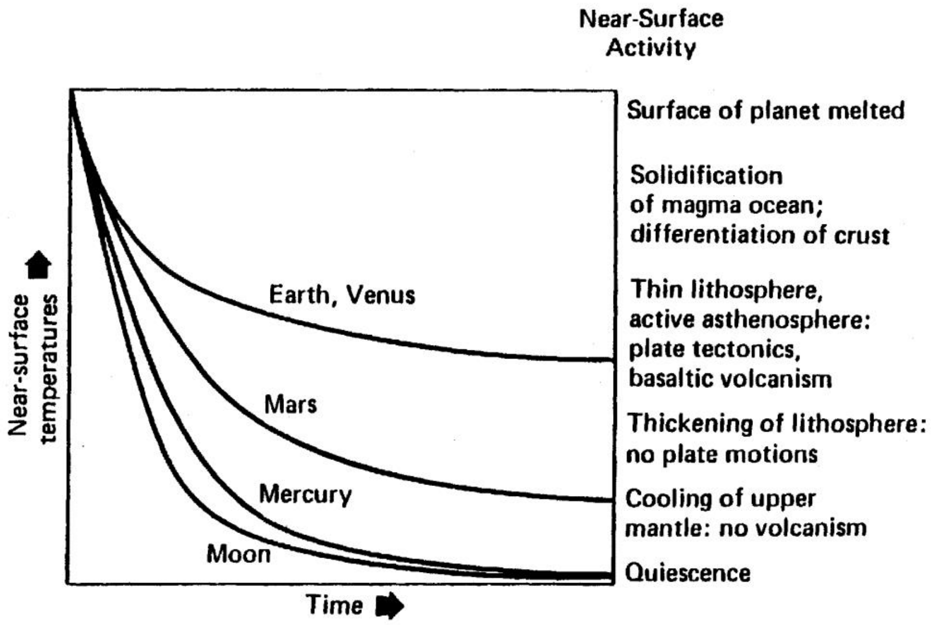
Mars

# Thermal History of the Terrestrial Planets

**Heat sources for early Earth**

- Accretion – material added to earth causes heating due to conversion of kinetic energy
- Radioactive decay (U, Th, and K)
- Core formation – conversion of potential gravitational energy to heat

**FIG. 7-13** A first-order explanation for differences in the present geologic state of the planets, based on the proposition that cooling of the outer layers of planets brings on different stages of geologic activity (right edge of diagram), and small planets cool faster than large ones.



# Characteristics of the Atmospheres of Venus, Earth and Mars

| | | | **Composition of Atmosphere (Vol %)** | | | | |
|---|---|---|---|---|---|---|---|
| | Surface T ($^oC$) | Surface P (Atm) | $CO_2$ | $N_2$ | $H_2O$ | Ar | $O_2$ |
| **Venus** | **468** | **99** | **96.4** | **3.4** | **0.14** | **18.6 ppm** | **69.3 ppm** |
| **Earth** | **15** | **1** | **0.033** | **78.084** | **Var** | **0.934** | **20.946** |
| **Mars** | **-63** | **0.0052** | **95.32** | **2.7** | **0.03** | **1.6** | **0.13** |

## Origin of the Atmospheres

- Primary – left over from the formation of the solar system
- Secondary – formed after construction of the planet

Primary Atmosphere – left over after the escape of the lighter (less massive) gases

Average thermal velocity of an atom or molecule

$$v_i = 2\sqrt{\frac{2kT}{\pi m_i}}$$

k = Boltzman constant, T = K, $m_i$ = mass in grams of a particular atom or molecule

For a residual (primary) atmosphere the abundance ratio for two massive and non-reactive elements should be the same for the sun as the earth

N/Ne (sun) = 0.85 N/Ne (earth) = 40,000

Earth's atmosphere isn't residual

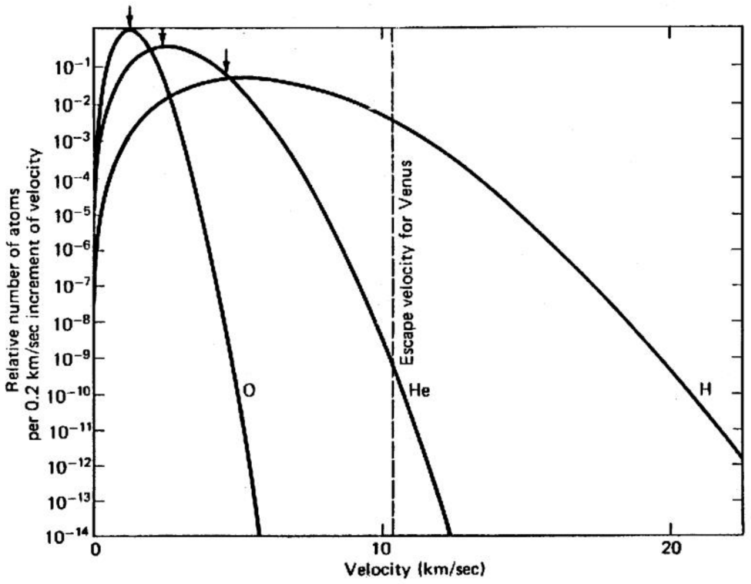
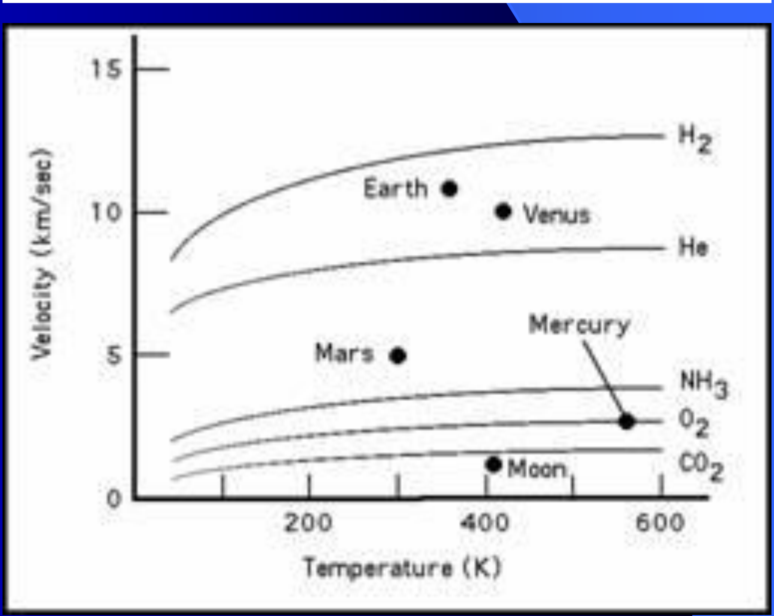


**FIG. 4-8** The Maxwell distribution of velocities among atoms of three gases at 1,000°K. Arrows indicate the mean velocity ($v_i$) for atoms of each species. Note that the vertical axis, expressing relative abundances, is a logarithmic scale encompassing many factor of 10. Atoms of light gases are in more rapid motion that heavy gas atoms, so are more likely to escape from a planetary atmosphere into space. In the example shown, ~1 percent of the hydrogen atoms are moving at greater than the escape velocity of Venus, but only ~3 × $10^{-10}$ of the helium atoms are. At lower temperatures, all three curves would contract to smaller velocity ranges.



# Holland’s Three Stage Model for the Origin of the Earth’s Atmosphere

1) First Stage – prior to core formation. Native iron present. Volcanic gases are highly reduced. $H_2$, $CH_4$, $NH_3$. 4.5 to 4.0 Ga.

2) Second Stage – after core formation. Atmosphere becomes less reducing. Major changes are $CO_2$ replacing $CH_4$ and $N_2$ replacing $NH_3$. 4.0 to 2.0 Ga.

3) Third Stage – photosynthesis initiated and free oxygen builds up. Large banded iron formations do not form after 2.0 Ga which indicates a build-up in oxygen which inhibits the transport of iron in solution. 2.0 Ga to present

## Other patterns deduced from the geologic record:

1) The concentration of various gases in the atmosphere has varied throughout geologic time.

2) There have been times in the past when oxygen content has been much greater than today (30% versus 21%) and spontaneous wildfires have occurred.

3) Carbon dioxide concentrations in the atmosphere have been both significantly lower and significantly greater than at present.

# Venus and Earth are very similar planets in terms of size and density. Why are their atmospheres so different?

- Total amount of C, H, and N in the surface reservoirs for both planets are very similar but they are found in different reservoirs – atmosphere for Venus; hydrosphere, polar caps and sediments for Earth.

- Relative to Venus and Earth, very little C, H, and N in Mars surface reservoirs. Because Mars is smaller than Earth and Venus its active thermal history is much shorter. A lot less degassing.

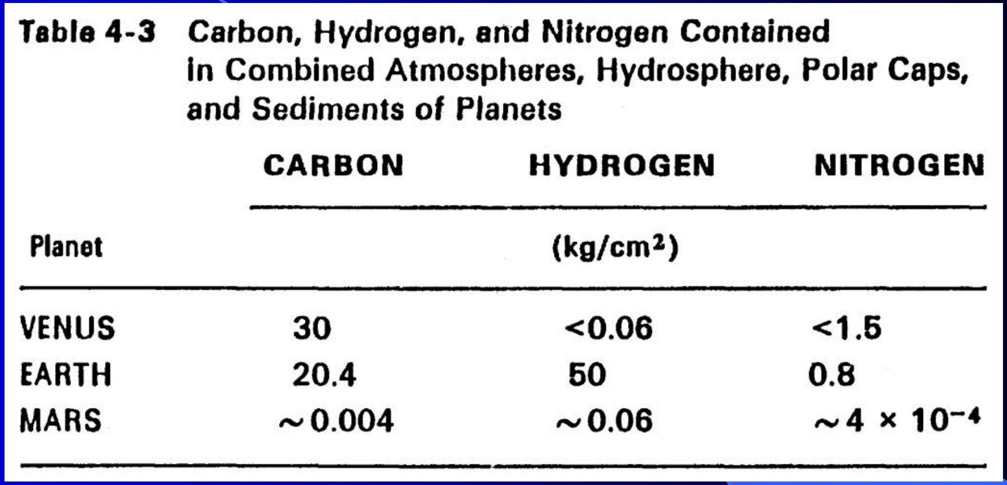


**Table 4-3** Carbon, Hydrogen, and Nitrogen Contained in Combined Atmospheres, Hydrosphere, Polar Caps, and Sediments of Planets

| Planet | CARBON | HYDROGEN | NITROGEN |
|---|---|---|---|
| | | ($kg/cm^2$) | |
| VENUS | 30 | <0.06 | <1.5 |
| EARTH | 20.4 | 50 | 0.8 |
| MARS | ~0.004 | ~0.06 | $\sim 4 \times 10^{-4}$ |

So why are Venus and Earth different? It all has to do with liquid water versus water vapor. Liquid water formed on Earth, not on Venus. Carbon dioxide was removed from the Earth’s atmosphere by photosynthesis and oxygen was added. Life did not develop on Venus. Mars may be a different story, but the limited amount of degassing inhibited the process.

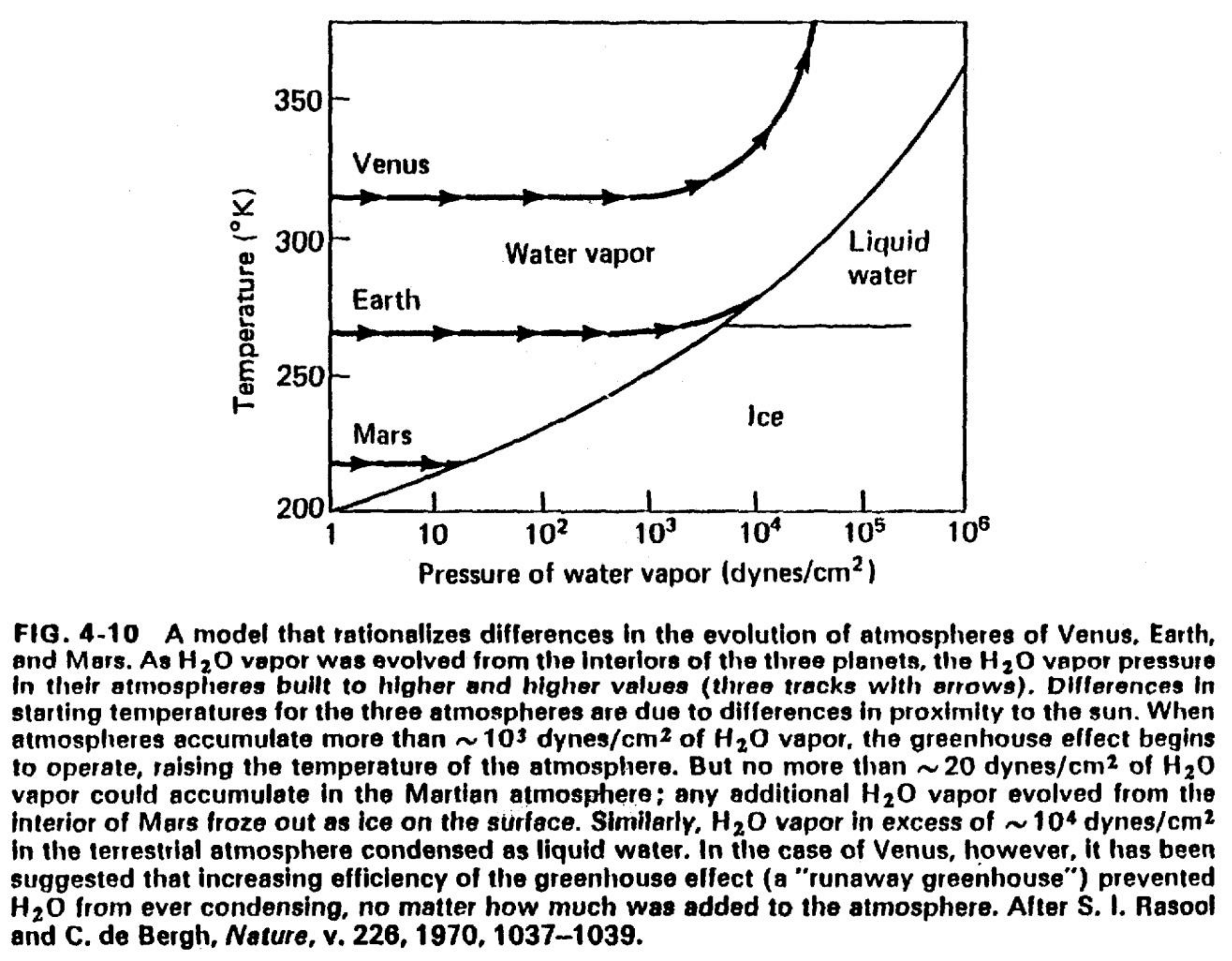


**FIG. 4-10** A model that rationalizes differences in the evolution of atmospheres of Venus, Earth, and Mars. As $H_2O$ vapor was evolved from the interiors of the three planets, the $H_2O$ vapor pressure in their atmospheres built to higher and higher values (three tracks with arrows). Differences in starting temperatures for the three atmospheres are due to differences in proximity to the sun. When atmospheres accumulate more than $\sim 10^3$ dynes/cm$^2$ of $H_2O$ vapor, the greenhouse effect begins to operate, raising the temperature of the atmosphere. But no more than $\sim 20$ dynes/cm$^2$ of $H_2O$ vapor could accumulate in the Martian atmosphere; any additional $H_2O$ vapor evolved from the interior of Mars froze out as ice on the surface. Similarly, $H_2O$ vapor in excess of $\sim 10^4$ dynes/cm$^2$ in the terrestrial atmosphere condensed as liquid water. In the case of Venus, however, it has been suggested that increasing efficiency of the greenhouse effect (a "runaway greenhouse") prevented $H_2O$ from ever condensing, no matter how much was added to the atmosphere. After S. I. Rasool and C. de Bergh, *Nature*, v. 226, 1970, 1037–1039.