HEATING OF AN ACCRETING PROTOPLANET BY BLANKETING EFFECT OF A PRIMARY SOLAR-COMPOSITION ATMOSPHERE:

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When planetary accretion proceeds in the presence of the solar nebula, a growing protoplanet attracts the surrounding nebular gas to form a gravitationally-bound H_2-He atmosphere after planetary mass exceeds 1.4×10^{22} $(T/280[\mathrm{K}])^{3/2}$ $(\bar{\rho}/4000[\mathrm{kg/m^3}])^{-1/2}$[kg]. The atmosphere is extended to the gravitational radius where gravitational energy and gas thermal energy are balanced: it is 60 times as large as the planetary radius at the Earth's mass ($1\mathrm{M_E} = 5.97 \times 10^{24}$[kg]).

The attracted atmosphere becomes the present envelope of a Jovian-type planet after the atmosphere collapses on to the central body by its self-gravity *(1, 2, 3)*. As for a terrestrial planet whose mass is too small for the atmospheric collapse, the solar-type atmosphere, if present, may enhance temperature at the planetary surface since the blanketing effect of optically-thick gas prevents free escape of accretional energy *(4, 5, 6)*.

The surface temperature exceeds melting temperature of silicate when the planetary mass reaches 1×10^{24}[kg]. The molten silicate or metal-oxide at the planetary surface is reduced by atmospheric H_2 and a large amount of H_2O vapor is formed *(7)*. Under a probable oxygen buffer (quartz-iron- fayalite or iron-wüstite) system, partial pressure ratio P_{H_2O}/P_{H_2} should be 0.1~0.3 in a wide temperature range. Then abundance of oxygen atoms in the atmosphere (mostly in H_2O) becomes 100 times enhanced from the solar value (see Fig.1). The additional H_2O raises gas temperature by increasing both atmospheric opacity and gas molecular weight. The former also renders the atmosphere convectively unstable. In effect, the balance of enhanced molecular weight (~ 4) and H_2 dissociation (which suppresses adiabatic gradient) determines a temperature curve of the atmosphere. The surface temperature is raised to 4000[K] (at Venus' mass: $0.8\mathrm{M_E}$) and 4700[K] (at Earth's mass) *(7)*. This is much higher than the temperature caused by impact-induced atmosphere (~ 1600[K]: melting temperature *(8)*).

In the above estimate, H_2O enhancement is limited to the lower region where temperature is higher than 1000[K], assuming decomposition of hydrous minerals which determines the initial H_2O supply. And at constant dust abundance, convective zone is limited and extensive mixing would not be plausible. But at low pressure the decomposition (hydration) temperature should be much lowered and dust materials may not work as a sink of H_2O. Variation of dust abundance might cause convective heat transport in the outer region, and moreover, incoming planetesimals would stir the atmosphere. Therefore we newly performed calculations where H_2O is enhanced throughout the atmosphere where the outer boundary is the gravitational radius. One result is shown in Fig.2. Initially in the outer region, temperature gradient is steeper than that of the previous case (denoted by the dashed curve where H_2O increase starts at T=1000[K]). But at the bottom region, temperature is suppressed due to dissociation of H_2. The resulting surface temperature is 5100[K] and similar to the previous value.

Anyway such a high temperature may form a deep totally- molten magma ocean. And different from the extensive heating by a giant impact, timescale of the ocean blanketed by the thick atmosphere could be as long as the life-time of the solar nebula ($\sim 10^6 - 10^7$[yr]). Metal-silicate fractionation, i.e., core formation would be very rapid and have proceeded concurrently with accretion.

Numerical calculations are performed by RVAX at University of Arizona and Cyber 205 at John von Neumann National Supercomputer Center.

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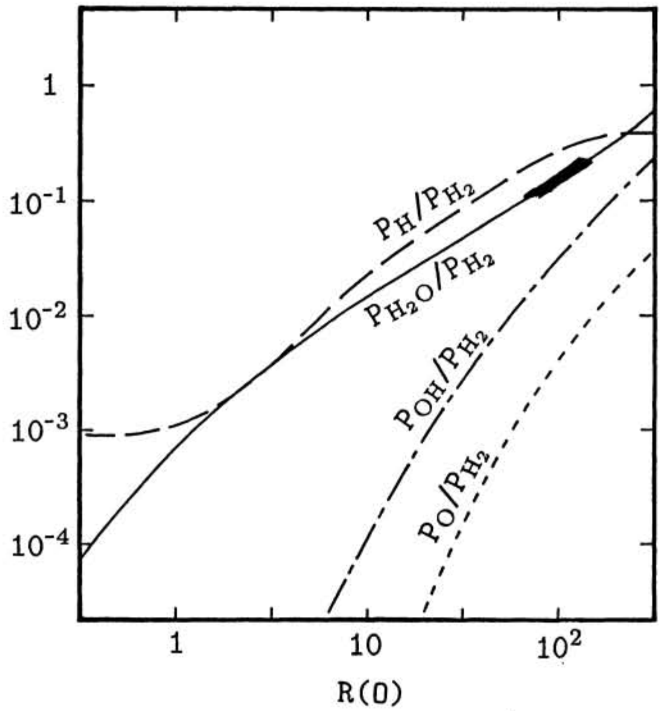

Figure 1 Partial pressure ratios measured at the planetary surface for given value of R(O), which is relative oxygen abundance to hydrogen (normalized by solar value). The bold zone corresponds the probable value from quartz-iron- fayalite oxygen buffer. Note that $P_H/P_{H_2}$is still smaller than unity despite large effect of dissociation on the adiabat.

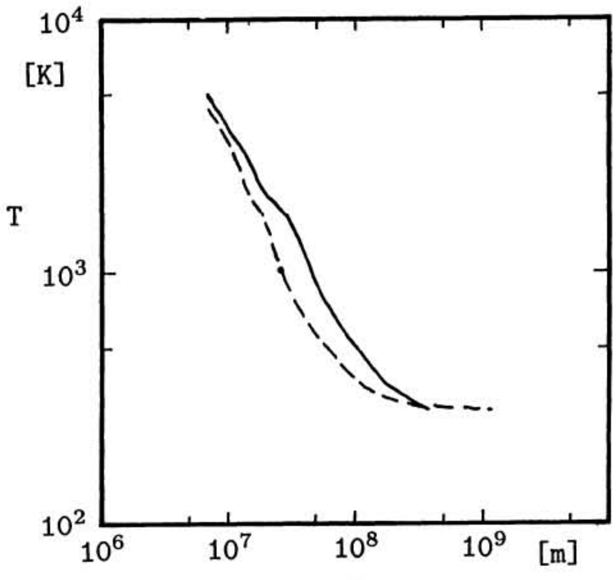

Figure 2 Temperature distributions. The horizontal axis is planetocentric distance. The solid curve expresses the case where R(O)=100 in the overall atmosphere, whereas the dashed curve is the case R(O)=100 where T>1000[K]. Planetary mass is $1M_E$. Dust abundance is 3×10^{-3}[kg/kg].