EPSC Abstracts,
Vol. 4, EPSC2009-661, 2009
European Planetary Science Congress,

The origin of Ganymede: implications for volatile content

O. Mousis (1) and Y. Alibert (1)

(1) Université de Franche-Comté, Institut UTINAM, CNRS/INSU, UMR 6213, 25030 Besançon Cedex, France (olivier.mousis@obs-besancon.fr / Fax: +33-381-666944)

Abstract

We use an evolutionary turbulent model of Jupiter's subnebula to constrain the composition of ices incorporated in its regular icy satellites [1]. We consider CO_2, CH_3OH, CO, CH_4, N_2, NH_3, H_2S, Ar, Kr and Xe as the major volatile species existing in the gas-phase of the solar nebula. All these volatile species, except CO_2 which crystallized as a pure condensate, are assumed to be trapped by H_2O to form hydrates or clathrate hydrates in the solar nebula. Once condensed, these ices were incorporated into the growing planetesimals produced in the feeding zone of proto-Jupiter. Some of these solids then flowed from the solar nebula to the subnebula, and have been accreted by the forming Jovian regular satellites. We show that ices embedded in solids entering at early epochs into the Jovian subdisk were all vaporized. This leads us to consider two different scenarios of regular icy satellite formation in order to estimate the composition of the ices they contain. In the first scenario, icy satellites were accreted from planetesimals that have been produced in Jupiter's feeding zone without further vaporization, whereas, in the second scenario, icy satellites were accreted from planetesimals produced in the Jovian subnebula. In this latter case, we study the evolution of carbon and nitrogen gas-phase chemistries in the Jovian subnebula and we show that the conversions of N_2 to NH_3, of CO to CO_2, and of CO to CH_4 were all inhibited in the major part of the subdisk. Finally, we assess the mass abundances of the major volatile species with respect to H_2O in the interiors of the Jovian regular icy satellites, including Ganymede.

Chemistry in the Jovian subnebula

The net reactions relating CO, CH_4, CO_2, N_2 and NH_3 in a gas dominated by H_2 are

$$\mathrm{CO + H_2O = CO_2 + H_2} \quad (1)$$

$$\mathrm{CO + 3H_2 = CH_4 + H_2O} \quad (2)$$

$$\mathrm{N_2 + 3H_2 = 2NH_3} \quad (3)$$

which all proceed to the right with decreasing temperature at constant pressure. Reaction (1) has a rate coefficient which is very low, even at temperatures as high as 2000 K [1]. Such a high temperature range is only reached at distances quite close to Jupiter and at early epochs in the Jovian subnebula. As a result, the amount of carbon species produced through this reaction is insignificant during the whole lifetime of the subnebula.

Reactions (2) and (3) are illustrated by Figs. 1 and 2. At equilibrium, CO:CH_4 and N_2:NH_3 ratios depend only on local conditions of temperature and pressure. CO:CH_4 and N_2:NH_3 ratios of 1000, 1 and 0.001 are plotted in Figs. 1 and 2, and are compared to our turbulent model at three different epochs (0 yr, 0.56 Myr and 0.6 Myr). These figures show that, when the kinetics of chemical reactions are not considered, CH_4 and NH_3 progressively dominate with time in the major part of our turbulent model of the Jovian subnebula rather than CO and N_2.

However, the actual CO:CH_4 and N_2:NH_3 ratios depend on the chemical timescales, which characterize the rates of CO to CH_4 and N_2 to NH_3 conversions in our model of the Jovian subnebula. Taking into account the kinetics of chemical reactions, we have inferred that the efficiency of the conversion is limited only to the inner part of the Jovian subnebula and at early times of its first phase. All these calculations imply that CO:CH_4, CO_2/CO and N_2:NH_3 gas phase molecular ratios remain almost constant during the whole lifetime of the Jovian subnebula. In these conditions, the composition of the ices produced within the Jovian subnebula is then close to that of the ices produced in the solar nebula [2] (see Table 1).

References

[1] Alibert, Y., Mousis, O. and Benz W. 2005, *Astronomy and Astrophysics*, 439, 1205–1213.

[2] Mousis, O., et al. 2009, *The Astrophysical Journal*, 696, 1348–1354.

EPSC Abstracts,
Vol. 4, EPSC2009-661, 2009
European Planetary Science Congress,

Table 1: Average composition of ices formed in the outer solar nebula. Composition of ices is calculated in the cases of 100% and 10% clathration efficiencies. Ratio of the mass of ice i to the global mass of ices (wt%) is determined from a gas phase composition given by [2].

Ice	100% clathration efficiency	10% clathration efficiency
H_2O	5.00×10^{-1}	5.22×10^{-1}
CO	2.78×10^{-1}	2.50×10^{-1}
CO_2	1.13×10^{-1}	1.17×10^{-1}
NH_3	3.60×10^{-2}	3.75×10^{-2}
H_2S	2.37×10^{-2}	2.26×10^{-2}
N_2	2.16×10^{-2}	2.25×10^{-2}
CH_3OH	1.93×10^{-2}	2.01×10^{-2}
Ar	4.49×10^{-3}	4.68×10^{-3}
CH_4	3.42×10^{-3}	2.23×10^{-3}
PH_3	8.21×10^{-4}	6.59×10^{-4}
Kr	7.40×10^{-6}	7.72×10^{-6}
Xe	1.86×10^{-6}	1.46×10^{-6}

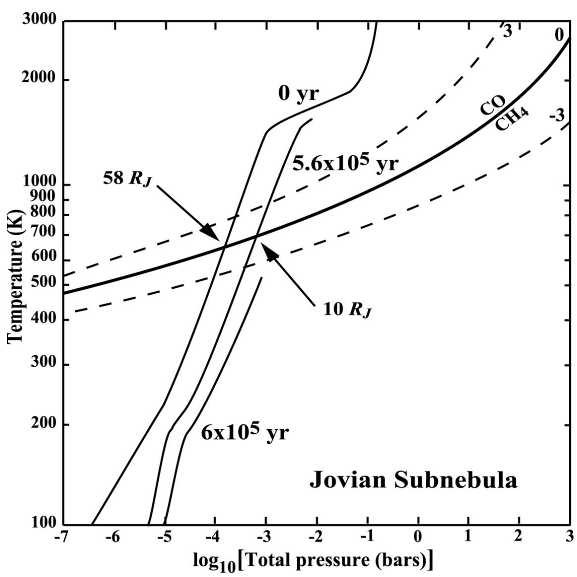

Figure 1: Calculated ratios of CO:CH_4 in the Jovian subnebula at the equilibrium. The solid line labelled CO-CH_4 corresponds to the case where the abundances of the two gases are equal. When moving towards the left side of the solid line, CO/CH_4 increases, while moving towards the right side of the solid line, CO/CH_4 decreases. The dotted contours labelled -3, 0, 3 correspond to $\log_{10}$ CO:CH_4 contours. Thermodynamical conditions in our evolutionary turbulent model of the Jovian subdisk are represented at three epochs of the subnebula. The Jovianocentric distance, in R_J, is indicated by arrows when CO:CH_4 = 1 for t = 0 and 0.56 Myr.

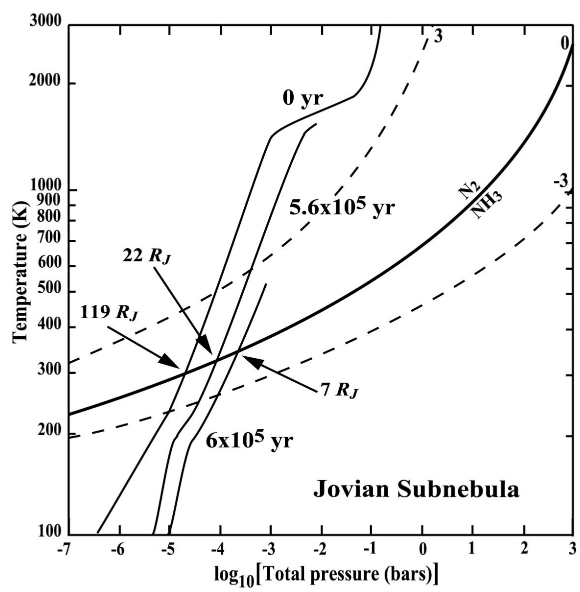

Figure 2: Same as Fig. 1, but for calculated ratios of N_2:NH_3 at equilibrium.