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THE ROLE OF FISCHER-TROPSCH CATALYSIS IN JOVIAN SUBNEBULAR CHEMISTRY

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Abstract. We examine the production of methane via Fischer-Tropsch catalysis in an evolving turbulent model of the Jovian subnebula and its implications for the composition of satellitesimals produced *in situ*. We show that there is a catalytically-active region in the Jovian subnebula from 65 Jupiter radii that moves inwards with time. The pressure range in this region is about 10^{-4} to 10^{-3} bar and implies that, if transport processes and the cooling of the subnebula are not considered, CO and CO_2 are entirely converted into CH_4 via Fischer-Tropsch catalysis in about 10^1-10^2 and 10^3-10^4 years, respectively. On the other hand, the comparison of the chemical conversion times with the viscous timescale of the subdisk in the catalytically-active region implies that only CO can be fully converted into CH_4, the conversion of CO_2 thus being restricted to a limited production of CH_4. Moreover, the time required by the Jovian subnebula to cool down from the optimal temperature for Fischer-Tropsch catalysis to the condensation temperature of ices is at least two orders of magnitude higher than the viscous timescale. This implies that any CH_4 produced in the catalytically-active zone will be accreted onto Jupiter long before being incorporated into the forming ices.

1 Astrophysical context

Fischer-Tropsch catalysis, which converts CO or CO_2 and H_2 into CH_4 on the surface of transition metals such as iron and nickel, is believed to play important roles in astrophysical environments. Laboratory experiments to determine CH_4 reaction rates under a hydrogen-dominated gas-phase and at low-pressure conditions, corresponding to those of the solar nebula, have been recently conducted by Sekine et al. (2005). In this work, we utilize these experimental data to examine the CH_4 production via Fischer-Tropsch catalysis in the Jovian subnebula and its implications for the composition of satellitesimals. In order to estimate the thermodynamic conditions within the Jovian subnebula, we also use the evolutionary turbulent model developed by Alibert et al. (2005a). From this model, Mousis & Alibert (2006) proposed that regular icy satellites may have formed from satellitesimals produced either in the solar nebula or in the subdisk. They also concluded that the chemical composition of ices incorporated in regular satellites is nearly identical in both formation scenarios, due to the inhibition of the homogeneous gas-phase chemistry in the Jovian subnebula. However, heterogeneous gas-phase chemistry was not taken into account in the afore-mentioned study. Therefore, we investigate here in which part of the Jovian subnebula Fischer-Tropsch catalysis may have been efficient and determine if the composition of satellitesimals produced *in situ* may be different or not from that of solids formed in the solar nebula.

2 Fischer-Tropsch catalysis

According to laboratory experiments (Sekine et al. 2005), at low pressures (2×10^{-2} – 5×10^{-1} bar) and high H_2/CO and H_2/CO_2 ratios (= 1000), the region of efficient conversions of CO into CH_4 and of CO_2 into CH_4 via Fischer-Tropsch catalysis is narrow in a subnebula (T = $\sim$ 550 K). Using the experimental data on CH_4

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formation rates, timescales for the conversions of CO into CH_4 ($t_{CO \rightarrow CH_4}$) and of CO_2 into CH_4 ($t_{CO_2 \rightarrow CH_4}$) at 550 K are estimated as a function of pressure in the gas-phase conditions of the Jovian subnebula. From the model of the Jovian subnebula developed by Alibert et al. (2005a), the pressure range encountered in the subdisk at 550 K is calculated to be about 10^{-4} to 10^{-3} bar. This pressure range is still high enough for CH_4 to dominate CO under chemical equilibrium. In this pressure range, if transport and cooling processes are not taken into account in the Jovian subnebula, CO and CO_2 are entirely converted into CH_4 via Fischer-Tropsch catalysis in about 10^1-10^2 and 10^3-10^4 years, respectively.

3 Implications for the composition of ices formed in the Jovian subnebula

Fischer-Tropsch catalysis is efficient up to the distance of 65 $R_{\rm Jup}$ in the early Jovian subnebula since temperatures above 550 K are not reached at larger distances from the planet. Figure 1 shows the timescale $t_{viscous}$ required by an element of the subdisk to accrete onto Jupiter as a function of the planetary separation and when the local temperature is of 550 K. This momentum diffusion timescale is given by $t_{viscous} = 2r^2/3\nu$ where r and ν are the distance from Jupiter and the turbulent viscosity in the subnebula given by the model of Alibert et al. (2005a). This Figure also represents the timescale (Δt in Fig. 1) required for the subdisk to cool down from 550 K to the ice condensation temperature which is assumed here to be $\sim$ 150 K as a function of the distance from Jupiter. For a given planetary separation, the two timescales are calculated at the same epoch of the subnebula's evolution. The closer the distance of calculations is from Jupiter, the more evolved is the subnebula. It can be seen that, at a given planetary separation, $t_{CO \rightarrow CH_4}$ is shorter than $t_{viscous}$ whereas $t_{CO_2 \rightarrow CH_4}$ is longer than $t_{viscous}$. This implies that only CO can be completely converted into CH_4 via Fischer-Tropsch catalysis in our evolving model of the Jovian subnebula, the conversion of CO_2 into CH_4 being much less efficient. In order to determine if the resultant methane can be incorporated in ices formed in the Jovian subnebula, $t_{viscous}$ must be compared with Δt. From Fig. 1, it can be seen that Δt is still at least two orders of magnitude higher than $t_{viscous}$ in the zone of the Jovian subnebula where Fischer-Tropsch catalysis is efficient. This implies that any methane produced in the catalytically-active zone will be accreted onto Jupiter long before having being incorporated into the forming icy grains. From these calculations, we can infer that in an evolving turbulent subnebula, even if Fischer-Tropsch catalysis is active, it has no influence on the composition of the forming microscopic icy grains.

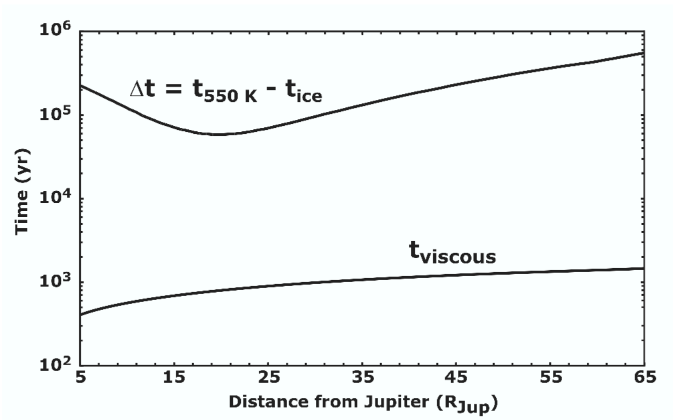

Fig. 1. From top to bottom: time needed by the subnebula to cool down from 550 K to the condensation temperature of water ice (150 K) and viscous timescale of the subdisk as a function of the distance from Jupiter.

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