THERMODYNAMIC EQUILIBRIUM CONDENSATION FOR DUST ENRICHED SOLAR GAS. A. Gupta[1], S. Sahijpal[1]. [1]Department of Physics, Panjab University, Chandigarh, 160014, India; e-mail: mr.anuj@pu.ac.in

Introduction: The signatures of the various physico-chemical processes that occurred in the early solar system are recorded in the meteorites in the form of early condensed dust grains. The presence of these dust particles with a wide range of chemical composition provides an opportunity to explore and understand the environment which is not possible otherwise in the laboratory. The focus of the present work is to develop a comprehensive theoretical framework of thermodynamics associated with the condensation of various solid phases and solid-solutions in the fractionated solar nebula. A vast variety of fractionated systems can be modelled for spatially localized compositions. Here, we present the detailed thermodynamical equilibrium calculations for the fractionated solar gas with an enhanced (250×) dust to gas ratio at pressures ranging from 10^{-2} to 10^{-6} bar. We adopted the recently revised solar metallicity of 0.014 and updated thermodynamic data.

In order to increase the oxidizing state of the condensing environment we have assumed the mixing of C1 dust with the solar gas. Subsequent to the anticipated vaporization and localized homogenization of the dust grains in the nebula the condensation sequence was deduced for several scenarios. We adopted the procedure from the earlier work to enhance the dust to gas ratio [1]. The composition of the C1 chondritic dust [2] has been chosen. The computation of the chemical equilibria requires the minimization of the chemical potential of the system assemblage of a given composition. The formulation developed by previous work [3,4] was used to develop the numerical code for the mineral equilibria for multiphase system. A novel numerical code [5] has been developed in Python in order to investigate the thermodynamics of the dust grain condensation in the considered localized region of the cooling solar nebula.

Result and Discussion: We have run the simulations for the calculation of the temperatures of appearance and disappearance of the various condensates in the system assemblage of distinct compositions at different pressures. The calcium and aluminum refractory phases (Table 1) are predicted to initially condense in a reducing environment [6,7]. On the contrary, Ti-rich oxides like armalcolite ($MgTi_2O_5$), Mg_2TiO_4 and geikilite ($MgTiO_3$) have been found to be stable for dust enriched compositions. This is in general agreement with the observations based on the chondritic data [8,9]. The results in terms of the mineralogical sequence corresponding to 250× dust enriched system at 10^{-2} and 10^{-3} bar pressure have been presented in Table 2. The names of the solid-solutions are mentioned, whereas, the pure solid phases are presented by their formulae.

Table 1. The appearance and disappearance temperatures (in K) of condensates for solar gas.

	P = 10^{-2} bar		**P = 10^{-3} bar**	
Condensate	*In (K)*	*Out*	*In (K)*	*Out*
Al_2O_3	1808	1807	1735	1706
$CaAl_{12}O_{19}$	1807	1568	1709	1480
$CaTiO_3$	1748	1466	1665	1392
Melilite	1703	1466	1612	1410
Spinel	1568	1422	1480	1356
Metal-Alloy	1566		1456	
Olivine	1502		1424	
Fassaite	1466		1410	
Ti_2O_3	1466	1352	1392	1370
Plagioclase	1427		1360	
Clinopyroxene	1397		1332	
Ti_4O_7	1352	1141	1370	1139
$CaTiSiO_5$	1141		1139	
Cr_2O_3	1030		1030	

Table 2. Mineralogical condensation sequence in a gas with a dust enhancement factor of 250.

	P = 10^{-2} bar		P = 10^{-3} bar	
Condensate	*In (K)*	*Out*	*In (K)*	*Out*
$CaAl_2O_4$	-	-	2320	2219
Melilite	2485	2116	2250	1771
$CaAl_{12}O_{19}$	-	-	2219	2191
Al_2O_3	2354	2197	2191	2023
Spinel	2198	1786	2024	1741
Ti_4O_7	-	-	1756	1739
$MgTi_2O_5$	1940	1389	1914	1901
Mg_2TiO_4	2047	1940	1901	1836
Olivine	2024		1886	
$Mg_7Si_8O_{22}(OH)_2$	1929	1765	-	-
$MgTiO_3$	-	-	1836	1756
Metal-alloy	1890		1731	
Fassaite	2117		1771	
Plagioclase	1786		1745	
TiO_2	-	-	1739	1443
Clinopyroxene	1765		1721	
Cr_2O_3	1691		1649	
$CaTiSiO_5$	1389		1443	
FeS	1256		1219	

Conclusion: A novel thermodynamical code has been developed in the present work and the stability field of all the solid condensates has been computed in the explored fractionated compositions. The condensation sequence, the distribution of the major elements between solid and vapor, and the condensation reactions have been computed.

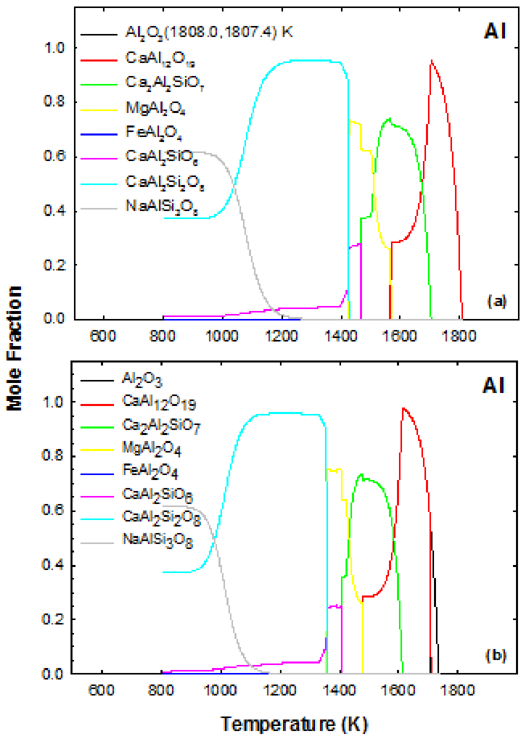
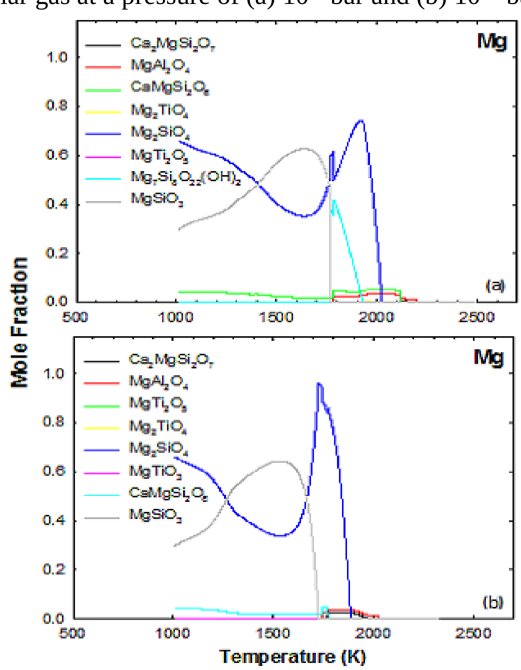


Fig 1. The distribution of Al between crystalline phases and vapour as a function of temperature for a solar gas at a pressure of (a) 10^{-2} bar and (b) 10^{-3} bar.



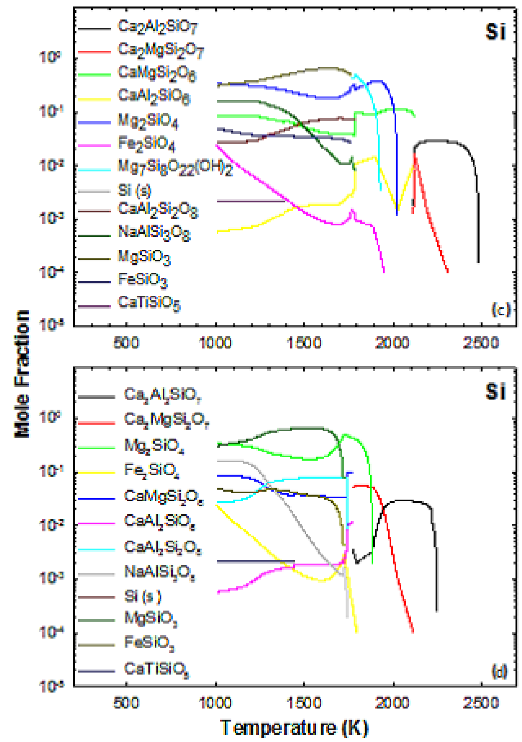


Fig 2. The distribution of Mg and Si in a gas enriched in C1 dust by a factor of 250 relative to solar gas at pressure of (a,c) 10^{-2} bar and (b,d) 10^{-3} bar.

Our models indicate the possibility of the oxides like armalcolite ($MgTi_2O_5$) and geikilite ($MgTiO_3$), which have been observed in Ningqiang meteorite, a stony C3- ungrouped chondrite. Similarly, a wide variety of compositions can be explored to explain the presence of various minerals found in ungrouped chondrites. Anthophyllite ($Mg_7Si_8O_{22}(OH)_2$), an inosilicate found in traces in Allende meteorite, has also been found to be stable in the present study.

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