EXPERIMENTAL EVIDENCE FOR GAS PHASE TRANSPORT OF SIDEROPHILE ELEMENTS IN THE SOLAR NEBULA. R. Dohmen[1], H. Palme, S. Chakraborty, and W. Rammensee, Institut für Mineralogie und Geochemie, Universität zu Köln, Zülpicher Str. 49 b, 50674 Köln, [1]dohmenr@min.uni-koeln.de.

Abstract. Millimeter sized, fine grained, spinel-rich inclusions (FGI) are found in all CV-chondrites. FGI in meteorites of the oxidized subgroup of CV (e.g., Allende) have comparatively high contents of volatile elements such as Na, K, Br, Cl, and also of the siderophile elements Fe, Ni, Co, and Ga. FGI are metal-free and have extremely low Ir contents. High temperature experiments with meteoritic metal and pure Mg-spinel demonstrate that the siderophile elements Fe, Ni and Co are transported from the meteoritic metal to the spinel by the gas phase. Ratios of FeO, NiO and CoO in spinels from experiments are identical to the ratios found in Allende FGI. The present experiments provide further strong evidence for the importance of gas-solid reactions at high temperatures in the early solar nebula.

Introduction. FGI have unique properties suggesting that they are condensation products in the early solar nebula: (a) FGI have unusual REE patterns produced by condensation after removal of an ultrarefractory component from the nebula [1]. (b) Allende FGI have large excesses of ^{129}Xe indicating that they have acquired large amounts of ^{129}I ($T^{1/2}$ = 17 my) early in the history of the solar system [2]. Further, FGI have very low concentrations of highly siderophile elements such as Ir, Pt, etc. (e.g., [3]). Comparatively high concentrations of some volatile elements (Na, K, Cl, Br, Zn) are characteritistic of FGI from Allende and other meteorites of the oxidized subgroup (Grosnaja, Bali) in contrast to meteorites of the reduced subgroup (Leoville, Efremovka, Vigarano, Arch). In FGI of Allende volatile element enrichments are accompanied by enrichments of Fe, Ni, and Co in spinel. Equilibration of FGI with the surrounding nebular gas at succesively lower temperatures has been suggested as source of FeO and volatile elements in FGI of CVO-meteorites [4]. The absence of a metal phase reflected by the low Ir contents and the enrichment of Fe as hercynite component in spinel suggested that Co and Ni entered the inclusions as oxides [5].

We have recently shown that solid phases, not in physical contact with each other, may react through gas phase transport [6]. Formation of fayalitic rims on forsterite grains, commonly found in Allende, was simulated by appropriate experiments. In order to test a similar origin for the hercynite component of spinel in FGI we did a series of new experiments.

Experiments. We have performed Knudsen cell mass spectrometry (KMS)-experiments to study the incorportaion of FeO, NiO and CoO into FGI by gas-solid reactions. The experiments are similar to those described earlier to simulate faylitic rim formation [6]. Powdered Canyon Diablo iron meteorite and fine grained Al, Mg-spinels were inserted together, but without physical contact, into the Knudsen cell. The assemblage was heated to 1300 °C for 20 hours and to 1400°C for 10 and 20 hours. Meteoritic metal and spinels were, before and after the experiments, analysed by instrumental neutron activation analysis (INAA). The products were characterized using X-ray diffraction. Polished sections of the spinel fractions were prepared and analyzed with the electron microprobe. Similar experiments were made with a fine grained forsterite fraction.

Results. KMS shows that Mg-spinel evaporates incongruently according to: $MgAl_2O_4$ (s) -> Mg (g) + 0.5 O_2 (g) + Al_2O_3 (s). However, the presence of metal in the experiment leads to a higher Mg partial pressure. X-ray diffraction shows that initial Mg-spinel remains spinel after the anneal. No other phases were observed. INAA results are shown in Table 1. Annealed spinels have higher concentrations of the siderophile elements Fe, Ni, Co, and Au. The stoichiometry of spinel analyzed by EMP indicates that FeO has replaced MgO in the spinel structure. The same is probably true for NiO and CoO. In contrast to Ni and Co, elements like Ga, Zn, and Na are depleted in the run products compared to the initial spinel composition. These elements were lost by effusion out of the Knudsen-cell during the anneal because they are too volatile for the temperatures chosen (Fig. 1).

Preliminary data from experiments with forsterite indicate a similar enrichment pattern as in spinel (Table 2).

Table 1. INAA of spinel samples before and after experiments

	Starting composition	1300 °C 20 h	1400 °C 20 h
Fe (%)	0.01	2.6	5.4
Co (ppm)	0.9	10.5	44.8
Ni (ppm)	35	40	392
Au (ppb)	1.5	8.6	9.6
Ga (ppm)	70.9	12	1.5
Zn (ppm)	13	10	4.4
Na (ppm)	1081	227	335

Table 2. INAA of an olivine sample before and after the experiment

	Fe (%)	Ni (ppm)	Co (ppm)
Starting composition	0.014	<10	0.405
1400 °C 20 h	11.6	288	42

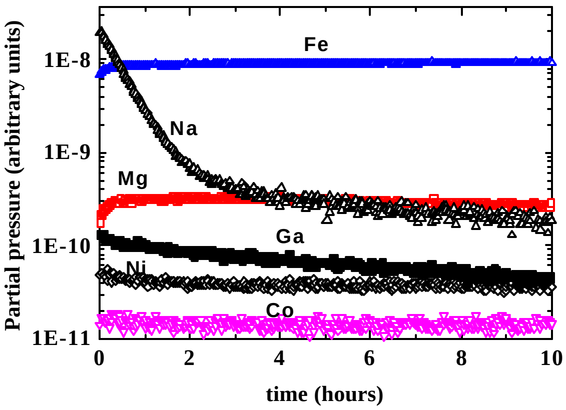
Discussion. The results clearly show that Fe, Ni and Co are transported through the gas phase from the meteorite to spinel and olivine. The reaction leading to

FeO-enriched spinels is similar to reactions proposed earlier for replacing MgO by FeO in olivine [6]:

$$MgAl_2O_4\,(s) + Fe\,(g) = FeAl_2O_4\,(s) + Mg\,(g) \qquad (1)$$

probably with analogue reactions for NiO and CoO. The source of gaseous Fe, Ni and Co in (1) is the Canyon Diablo meteorite (Fig. 1) with approximately solar ratios of Fe, Ni and Co. According to (1) elemental Mg is lost to the gas phase.

Figure 1. Measured partial pressures of an experiment during annealing at 1400 °C



In Figs. 2a and 2b we have plotted Fe, Co and Ni contents of Allende FGI. The Fe/Ni and Fe/Co ratios of FGI are distinctly different from CI-ratios. The spinels produced in the present experiments have Fe, Ni and Co concentrations very similar to those in FGI. This suggests that the non-chondritic Fe/Ni and Fe/Co ratios result from a combination of thermodynamic activities of FeO, NiO and CoO in spinel and of vapor pressures of the metals, implying that metal-spinel equilibrium progressed by gas phase transport.

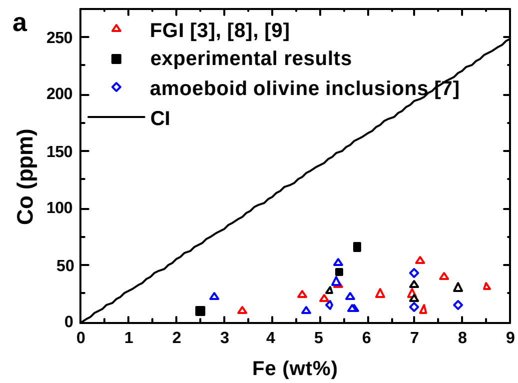
Illmenite rims around perovskite also observed in FGI [5] were probably formed by an analogue exchange reaction:

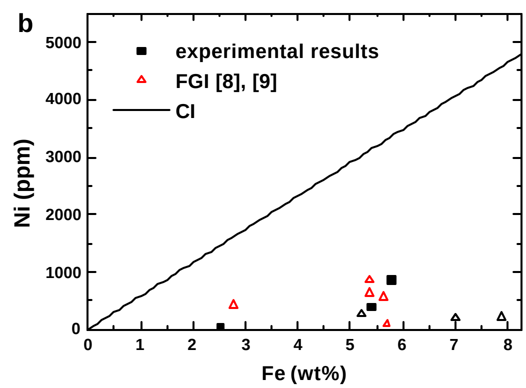
$$CaTiO_3\,(s) + Fe\,(g) = FeTiO_3\,(s) + Ca(g) \qquad (2)$$

KMS-experiments to test this hypothesis are in progress.

Conclusions. The experimental results of the present study confirm earlier evidence of gas-solid reactions [6] in the early solar system. Reactions similar to (1) must have played an important role at a time when condensed solid particles were still embedded in the solar gas. Gas-solid interactions are not single, well defined evaporation or condensation events. Continuous evaporation and condensation processes followed by solid state diffusion must have occurred [6]. A further consequence of this is that all components of oxidized CV-chondrites were affected by the redistribution of Fe, leading to formation of fayalitic rims and halos as shown earlier [6]. This must have occurred at higher oxygen fugacities than normally assumed for the solar nebula [4]. The lack of evidence for this kind of reactions in reduced subgroup meteorites either reflects permanently reducing conditions or very fast cooling which would not allow for gas-solid reactions.

Figure 2. (**a**) Co/Fe and (**b**) Ni/Fe ratios in processed spinels are similar to the ratios in FGI and amoeboid olivine inclusions of Allende. Both ratios are non-chondritic.





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