Introduction: Compelling observational evidence for extensive vapor phase transport on the Allende parent body has been in the literature for many years [1]. This evidence includes 1) widespread observations of disequilibrium Fe-rich olivine on surfaces and in internal cracks in MgSiO4, 2) widespread occurrences of isolated grains of low temperature pentlandite in the matrix, and 3) vesicle-like largely empty pores where metal/sulfide droplets had initially been in chondrules. It was suggested [1] that this vapor transport took place on a body that initially incorporated significant amounts of ices and was subsequently heated on a short time scale by extinct radionucleides. The possible gas phase species involved in this transport have not discussed until now. This work remedies that omission, and shows that at least Fe, Si, Mg, and Ni are indeed highly mobile as hydroxide molecules.

Thermodynamic Approach: All calculations have been done using the Gibbs Solver in the commercial HSC5 thermodynamics program from Outokumpu Research. The internal database contains all relevant data from the JANAF [2] and Glushko [3] compilations. This has been augmented with theoretical data on Cr containing molecules from Ebbinghaus [4] and on Si molecules from Allendorf et al [5]. This combination provides enough data to do meaningful calculations even though there are undoubtedly relevant molecules omitted because of lack of data.

Since by definition the solids in an unequilibrated meteorite are not in equilibrium with each other, the gas phase cannot be in global equilibrium with the solids. To estimate possible vapor transport rates we instead calculate the gas phase species in local equilibrium with selected solids or groups of solids. To these solids we add 0.9 moles of Ar and 0.1 mole of H2O vapor and include in the system all gas phase species containing these and elements from the solids. We then calculate the composition that minimizes the Gibbs free energy of this system as a function of temperature at one atmosphere total pressure. The resulting mole fractions of vapor species correspond directly with their vapor pressures as long as these are low.

Results: Consider first the vapor species above a region containing only MgSiO3 and Mg2SiO4. The pressures of the dominant Si and Mg molecules are shown in the plot below.

If Mg2SiO4 alone is present it evaporates congruently with substantially lower pressures of both Mg(OH)2 and Si(OH)4. In the above case Mg2SiO4 solid forms as Si(OH)4 evaporates.

Considering next the likely more realistic case where Fe metal is also in equilibrium with the gas gives the results below. In this case the vapor pressures of Si(OH)4 and Mg(OH)2 are each somewhat reduced and olivine solid solution forms.

There is also a large vapor pressure of Fe(OH)2 which facilitates the formation of the olivine. Directly above Fe metal the pressure of Fe(OH)2 would be even a couple of log units higher than shown.

Evaporation: To develop a feeling for what these vapor pressures mean in terms of possible vapor phase transport we will use the case of Fe(OH)2 above Fe metal and assume an evaporation coefficient of one. In this case, which we recently discussed in connection with chromite lacework structures observed in Allende [6], if we take a time of 10,000 years, which is still short compared to the radionucleide heating time scale, at a log vapor pressure of –16 about 25 micrometers of material could evaporate, while at –11 about 2 meters could. Thus any vapor pressures above about log –
17 imply the possibility of significant vapor transport on the parent bodies. An example of the chromite lacework believed result from magnetite evaporation leaving exolved sub-micrometer chromite behind is shown in the SEM-BSE image below. The calculated pressures of Cr containing species are 10 log units smaller at 500 C explaining why the tiny chromite crystals can remain. Note the suspended euhedral olivine and the faceted olivine in the background.

Fe-rich Olivine: Now let us consider the new solids that form in the above case. Starting with pure Fe metal and MgSiO3 as precursor solids, but allowing pyroxene, olivine, and magnesiowustite solid solutions as possibilities, the solids which are predicted are shown below.

The Mg2SiO4 and Fe2SiO4 are in solid solution and the FeSiO3 is in the MgSiO3. This predicted composition of olivine is close to those observed in Allende matrix olivine and olivine overgrowths, which were earlier interpreted to result from parent body vapor phase transport [1].

The textures of enstatitic pyroxene, Fe-rich olivine intergrowths in Allende chondrules as illustrated in the SEM-BSE image following also strongly suggest that this olivine formed as a result of vapor phase transport.

Here the dark central area is enstatite while lighter gray areas around the edge and crossing the middle are Fe-rich olivine. Bright specks are sulfides. It has been experimentally confirmed that such textures can be easily produced by vapor phase transport [7] and no other explanation has ever been offered.

Pentlandite: Ni becomes almost as volatile as Fe as the hydroxide Ni(OH)2 as soon as all available Fe has been oxidized. Although that is rarely the case on a global scale it is probably generally the case on meteoritic alloy surfaces because of slow bulk diffusion in the metal. Hence we should probably also consider Ni volatile, and interpret isolated pentlandite grain in terms of vapor transport.

Implications: We have shown that Fe, Si, And Ni are mobile as hydroxides by 500 C, while Mg is by 700 C. In addition to the above this has important implications for oxygen isotope studies and CAI alteration.