A MODEL FOR THE FORMATION OF E CHONDRITES

Milton Blander¹ and Arthur Pelton²

¹ Quest Research, 1004 E 167th Place, South Holland, IL 60473-3114
² Ecole Polytechnique, CP6079 Succ. Centre-Ville, Montreal (Quebec), Canada

ABSTRACT

The purpose of this paper is to demonstrate that the formation of E chondrites from a gas of solar composition is consistent with the concepts of the “Constrained Equilibrium Theory” (Blander and Katz, 1967) which block the formation of metallic iron alloys and also forms metastable silicate liquid condensates which crystallize well below liquidus temperatures by more than 400 degrees or more. Constraints on iron condensation can be expected in terms of nucleation theories and leads to supersaturation of gaseous Fe which creates high iron chemical activities which increase as the temperatures decreases. This leads to the formation of FeO at activities much higher than the small equilibrium activities through the reaction

$$\text{Fe} + \text{H}_2\text{O} \leftrightarrow \text{FeO} + \text{H}_2$$

This reaction allowed us to determine from the FeO activities in Semarkona the relative temperatures of crystallization of all chondrule types which in turn allows us to calculate the compositions of each chondrule type accurately by the FACT computer program. All but one chondrule type theoretical calculations of compositions matched the measured chondrule compositions within the accuracy of the data. The one chondrule type which did not match the composition probably has inaccurately measured data on the relative amounts of type IA and IAB-IB.

Our calculation proved that the concepts of the “Constrained Equilibrium Theory” had major roles in forming Semarkona, and provides the probability that similar applications can use them for other classes of meteorites. Our theory is amazingly simpler and more accurate than so-called theories now believed. In this paper we will determine that the properties of E chondrules which are very different from ordinary chondrites, is consistent with the concept of the “Constrained Equilibrium Theory”.

In the formation of metastable silicate droplets the FeO concentrations are higher than equilibrium concentrations (about 0.1 wt%). We calculate from data of Wiik and Keil (Keil, 1968) and Schneider et al. (2002) that the maximum concentration of FeO in type EH chondrules are 8.41 wt% and 1.78 wt% for type EL chondrules. These quantities are deduced by data on chemical analyses by Wiik and by Keil on measurements calculated from modal and mineral compositions of Fe. In addition, we also used the data of Schneider et al. on the average compositions of chondrules. Since the data is from different chondrule types (those known in 1968 by Keil and type 3 chondrules by Schneider) there will be some uncertainties. The differences do not seem to be very large.

At these compositions, because of the high concentrations of Fe in the nebula, the high temperatures for E chondrites at these pressures (1 atmosphere) and a large supersaturation of
iron, can lead to a high probability for the condensation of iron as Fe-Ni alloys as suggested by nucleation theory. The reduction starts at compositions of FeO of 8.70 wt% for EH chondrules and 1.78 wt% for EL chondrules. Our calculated reduction of FeO to unalloyed Fe is 7.85 wt% of FeO for EH chondrules and 1.03 wt% FeO for EL chondrules. The average residual iron oxide in the data of Schneider et al. is 0.85 wt% for EH chondrules and 0.75 for EL chondrules. Since the precursor chondrule droplets crystallize as the temperature decreases, the first crystals formed would freeze in a relatively high FeO droplet because the reduction is not likely to be rapid because the reducing hydrogen has a small solubility in the droplet. The highest FeO contents measured by Schneider et al. is 4.6 wt% for EH3 chondrules and 1.9 wt% for EL3 chondrules. The other chondrules measured were all lower than these two numbers and the lowest ones were slightly larger than the equilibrium composition of a little less than 0.1 wt% FeO. The lower the FeO content of a chondrule suggests a lower temperature of crystallization.

Our calculations and observations explain the observations by Weisberg et al. (1994) in which the environment forms relatively high FeO in the precursor droplets (stage 1) and the environment changes when Fe-Ni alloys precipitate and FeO reduces to Fe (stage 2). In our work, this is not a change of oxidation but is a change allowing metallic iron to condense as mostly Fe-Ni alloys and iron forms in the reduction of FeO. The chondrules are never (or seldom) reduced to equilibrium compositions of FeO in the minerals.

Three of the four compositions of E chondrites chemically analyzed by Jarosewich (1990) leads to ratios of MgO/SiO$_2$, CaO/SiO$_2$ and Al$_2$O$_3$/SiO$_2$ which are smaller than expected in a solar composition. Our calculations on removal of some of the condensates suggests a loss of a large fraction of the condensates possibly by a wind (Shu, 1996) or, more likely, if close to the sun, by gravitational movement of a large fraction of the condensates toward the sun.