

**CONDENSATION FROM COSMIC GAS MADE OF FREE ATOMS.** D. S. Ebel<sup>1</sup> and L. Grossman<sup>1,2</sup>,  
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**Introduction:** It has long been known that the mineralogy of condensates from cosmic gases is strongly dependent on the atomic C/O ratio because of the great stability of the CO molecule [1]. If C/O > 1 as in C-rich stars, all O is combined as CO and the excess C is available to form graphite and carbides as high-temperature condensates. If C/O < 1 as in oxygen-rich stars, all C is combined as CO and the excess O is available to form oxides and silicates as high-temperature condensates. In meteorites, a significant fraction of interstellar graphite, and SiC grains of the X-type, are thought to have condensed from Type II supernova ejecta whose C/O ratio > 1. In order to explain details of the isotopic compositions of these grains, matter from interior zones of the supernova must be mixed with matter from the exterior. Mixing calculations which quantitatively reproduce the isotope ratios, however, invariably give C/O < 1 for the ejecta, from which graphite and SiC cannot condense [2]. As a way out of this predicament, Clayton [3] has suggested that supernova ejecta are so intensely irradiated that CO and other gas phase molecules are nearly completely dissociated, liberating C atoms from CO and making them available to form graphite and carbides, even in O-rich ejecta. While it is difficult to envision irradiation conditions which would prevent two atoms from bonding together to form a molecule while still allowing thousands of atoms to bond to one another to form a grain, we nevertheless performed condensation calculations from a gas of solar composition (C/O = 0.42) to see what condensate phases would form at equilibrium under two sets of conditions: (1) CO is prevented from forming; and (2) all polyatomic molecules are prevented from forming in the gas.

**Technique:** Calculations were done for a fixed total pressure of  $10^{-6}$  bars using the method of [4]. Runs were performed without the silicate liquid models described in [4], and were terminated when refractory elements such as Ti became depleted in the gas phase to a mole fraction of  $<10^{-20}$ .

**Results and Discussion:** When the CO molecule is prevented from forming, most of the oxygen forms CO<sub>2</sub> instead, reducing the partial pressure of oxygen by slightly more than one log unit at 1570K. Consequently, the phases corundum, hibonite, perovskite, melilite, spinel, pyroxene and olivine all appear at temperatures 40° to 60° lower than in a solar gas with CO present. Simple removal of CO does not cause graphite

or carbides to become stable in a gas of solar composition.

When all molecular species are prevented from forming, strange things happen. As predicted by Clayton [3], the C liberated from CO does condense as graphite, at 2110K. The O liberated from CO, however, is available to form oxide and silicate condensates at higher temperatures than in a fully speciated solar gas, in which the SiO molecule stabilizes Si in the vapor phase. In the present case, the free Si combines with the free O to condense cristobalite (SiO<sub>2</sub>) at 1860K, a higher temperature than that for any other refractory oxide, and after 99.6% of the carbon has already condensed as graphite. At 1820, Ti<sub>4</sub>O<sub>7</sub> condenses and is replaced by TiO<sub>2</sub> at 1790K, where mullite (Al<sub>6</sub>Si<sub>2</sub>O<sub>13</sub>) also appears. Anorthite (CaAl<sub>2</sub>Si<sub>2</sub>O<sub>8</sub>) appears at 1770K, and mullite disappears at 1750K. Spinel (CaTiSiO<sub>5</sub>) replaces TiO<sub>2</sub> at 1700K, wollastonite (CaSiO<sub>3</sub>) appears at 1680K, and whitlockite (Ca<sub>3</sub>(PO<sub>4</sub>)<sub>2</sub>) at 1610K. Wollastonite is replaced by diopside pyroxene (CaMgSi<sub>2</sub>O<sub>6</sub>) at 1590K. Cristobalite disappears at 1530K, just before forsteritic olivine (Mg<sub>2</sub>SiO<sub>4</sub>) finally appears at 1520K. In a solar gas composed entirely of monatomic species, at  $10^{-6}$  bars total pressure, graphite and cristobalite are the most abundant condensates between 2100K and 1600K.

Suppression of the polyatomic molecular species in a solar gas at  $10^{-6}$  bars total pressure changes the order of major element condensation from Al-Ca-Ti-Si-Mg to C-Si-Ti-Al-Ca-Mg. The mechanism called upon by Clayton [3] is unlikely to yield SiC or TiC grains, even if grains could nucleate in an environment which destroys gaseous molecules. Our calculations do suggest that, instead of SiC and TiC, SiO<sub>2</sub> would co-condense with graphite. One might expect extrasolar graphite to be accompanied by extrasolar silicon dioxide, if graphite did indeed form in the manner Clayton [3] suggests. Inclusions of SiO<sub>2</sub> have not been discovered in searches of extrasolar graphite.

**References:** [1] Larimer J.W. and Bartholomay M. (1979) *GCA*, **43**, 1455. [2] Amari S. and Zinner E. (1997) *Nuc. Phys.*, **A621**, 99c. [3] Clayton D.D. (1998) *LPS XXIX*, Abstract #1016. [4] Ebel D.S. and Grossman L. (1998) *LPS XXIX*, Abstract #1421.