A LARGE SCALE CARBON CYCLE MUST OPERATE THROUGHOUT THE SOLAR NEBULA.

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Introduction: Models of the interstellar grain population universally agree that carbonaceous and oxide grains are intimately mixed, either as separate populations of grains or as carbonaceous coatings on silicate cores (or some combination of both)[1]. A second universal feature of this dust population is a size range between ~0.25 micron and much smaller particles or even molecules, with virtually no mass in larger grains[2]. This small grain size distribution is the result of constraints imposed by cosmic chemical abundances, the mass-efficiency of dust absorption and scattering as a function of grain size and observational measurements of dust extinction along many lines of sight in the galaxy. This is the material that fell into the primitive solar nebula. Examination of the fine grain matrix in primitive meteorites reveals a much larger population of silicate grains ranging from micron-scale dust up to much larger particles several tens or even hundreds of microns in diameter [3]. It is quite clear that the initial population of silicate grains was thermally processed (sintered, melted or vaporized and recondensed) to a very large extent to form the fine grained matrix we observe in the most primitive solids. While some small fraction of the initial grain population has survived in meteorites, the vast majority (~99%) of pre-solar silicates has been thermally processed. A similar level of thermal processing must have occurred to pre-solar carbonaceous materials.

Effects of Thermal Processing: The effects of thermal processing depend greatly on the timescale. Transient events such as lightning and shocks can melt or vaporize small dust particles while barely heating much larger grains, or such processes can heat the exterior of larger particles while leaving the core unscathed. Carbonaceous coatings on silicate dust will certainly be heated and will react with the underlying silicate minerals to produce CO and reduced mineral phases. Small, oxide grain aggregates (that will include some carbonaceous dust) collapse to form larger, partially molten drops due to surface tension as they are heated. This leads to well-mixed, carbon/metal oxide systems that should efficiently react to produce CO plus partially reduced metal/metal oxide droplets. At sustained high temperatures such as are found in the innermost regions of the nebula even the largest dust grains will eventually melt or vaporize.

We argue that most of the material found in meteorites was processed through numerous transient high temperature events and not at sustained high temperatures, though this transient processing certainly began over a very wide range in initial temperatures depending on distance from the sun and the age of the nebula. The end result of such processing is chemically reduced silicates (possibly larger in size due to surface tension) and CO. Since aggregation and melting (or sintering) of silicates leads naturally to an ever larger grain size population, it is possible that most silicate grains were processed through multiple heating events, yet still remained nearly intact. It is therefore possible that our estimate that 99% of the initial dust population was processed through transient heating events (based on silicates) is an extremely conservative lower limit for carbon dust. If carbon is converted to CO during a single heating event, it is gone for good. While silicate solids are easily accreted into planetesimals, CO gas is not.

Carbon Depletion in the Solar Nebula: If ~99% or more of carbonaceous solids are converted to CO vis transient heating events in the solar nebula, then carbon should be significantly depleted in meteorites. However carbonaceous chondrites are only depleted by about a factor of 10 - 20 compared to dust in the ISM and ordinary and enstatite chondrites are down by about a factor of 10 - 100 [4]. There must be a mechanism to convert at least some of the initial CO gas falling in to the nebula, as well as the additional CO generated in transient heating events back into solid carbon (some fraction of which will itself be converted back into CO by later events) that operates throughout the nebula. We will describe our studies of the temperature dependent rate of Surface Mediated Reactions (SMR) and their efficiency in converting CO into carbonaceous solids [5]. This rate peaks at ~ 900K and decreases significantly at higher temperatures, yet graphite whiskers were observed to be associated with both CAIs and chondrules [6]. These whiskers are structurally very different from the solids deposited below 900K and might be formed via SMR occurring in a plasma-rich environmet [7]. Implications for the structure and abundance of carbon in meteorites will be discussed.

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