CONDENSATION OF CARBONACEOUS DUST IN THE HELIUM-RICH SUPERNOVA SHELL. T. Yu[1,2], B . S. Meyer[1], and D. D. Clayton[1], Department of Physics and Astronomy, Clemson University, Clemson, SC 29634-0978, USA. [2]5718 Kansas St. Houston, TX 77007, USA.

Introduction: It has long been suspected that the bulk of source material for condensation of presolar supernova graphite grains is from the helium-rich shell in the expanding stellar debris. This shell is the only place in the supernova in which carbon is more abundant than oxygen and, consequently, the only shell in which carbon will not be locked into CO (e.g., [1]) without some other effect hindering CO build up.

Subsequently it has been found that the requirement that C be more abundant than O for condensation of carbonaceous supernova dust may be relaxed due to break up of the CO molecule by fast electrons resulting from Compton scattering of gamma rays arising from ^{56}Co decay in the supernova material (e.g., [2] and references therein). The break up of CO leaves free carbon available for condensation of carbonaceous dust, even in regions with O>C. This effect may be of considerable significance for the recent finding of a large reservoir of cool dust in SN 1987A, which requires efficient condensation of carbon in the ejecta [3].

Despite the fact that it appears carbon can condense into dust in nearly all regions of core-collapse supernovae (such and SN 1987A), isotopic anomalies still point to the helium-rich shell as the dominant region for formation of the micron-sized presolar supernova dust found in meteorites. Perhaps most tellingly, several low-density supernova graphite grains show spatially correlated hotspots with excesses in ^{15}N and ^{18}O [4]. Such excesses are particular signatures of the helium shell (e.g., [5]).

To study the effect of fast electrons on condensation of carbon dust in the helium shell, we are applying the chemical network in [2]. We expect ^{56}Co to be present in or near this shell at the time of dust condensation either due to mixing of nickel-rich material from the inner regions of the ejecta (e.g., [6]) or due to extremely explosive helium burning in the inner part of the shell [7]. This radioactivity inhibits the growth of CO in the helium shell, just as in the oxygen-rich core.

The Presence of He^+: An interesting additional effect in the chemistry of the helium shell, not present in the helium depleted oxygen-rich supernova core, is the presence of He^+, which is produced by the fast electrons from ^{56}Co decay. This ion was observed in SN 1987A via the 1.083 micron HeI line, which results from recombination of HeII (He^+) [8]. That the line was present at late times strongly suggests the presence of ionization by fast electrons from ^{56}Co decay.

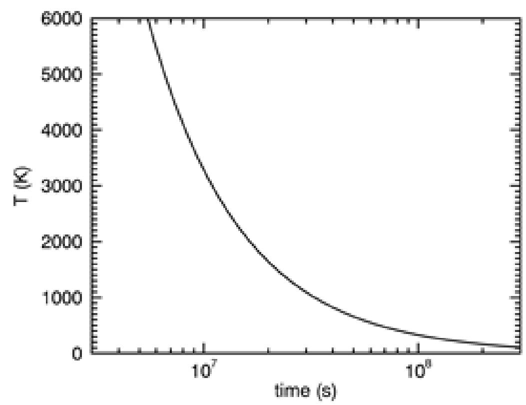

Figure 1

Network calculations: Destruction of CO by fast electrons in the oxygen-rich core occurs via the reaction $e^- + CO \rightarrow e^- + C + O$. The presence of He^+ adds the destruction reaction $He^+ + CO \rightarrow He^+ + C + O$. We have included this reaction in the network and performed exploratory calculations. We made two runs. The first (Run 1) included no effect from fast electrons. The second (Run 2) included break up from electrons and He^+. We used He, C, and O abundances appropriate for the helium shell and drew our thermodynamic trajectory from [2]. This trajectory is shown in Fig. 1. The calculation followed the expanding matter as it cooled from an initial temperature of 6000 K at about two months post explosion down to the final temperature of 100 K at about 10 years post explosion.

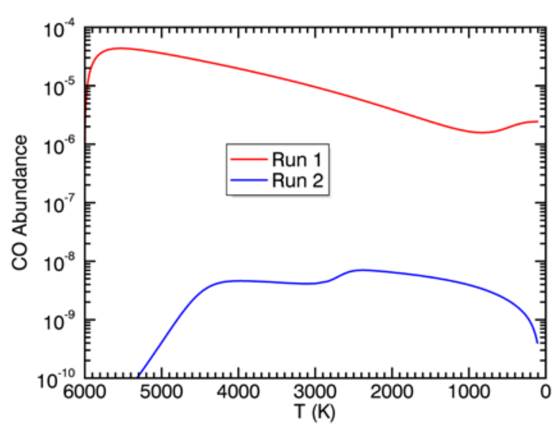

Figure 2

Fig. 2 shows the abundance of CO during the network calculations as a function of the cooling temperature in the two runs. In Run 1, CO builds up to a high value early because only disintegration reactions are hindering its production and those reactions decline in strength as the matter expands and the temperature cools. Later, CO declines due to other reactions. In Run 2 destruction reactions due to Compton electrons significantly prevent the build up of CO throughout the calculation.

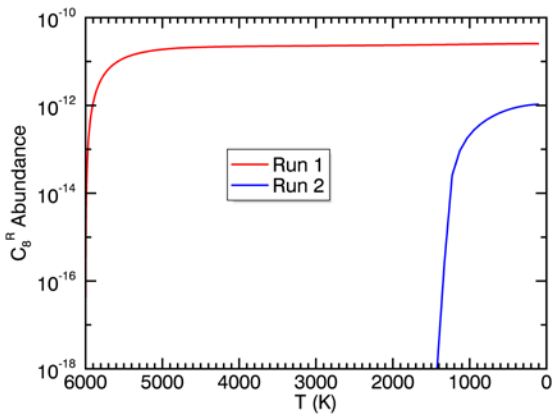

Figure 3

In [2], linear C_n molecules were taken to form via a sequence of fusion reactions such as C + C $\rightarrow$ C_2 + γ, C_2 + C $\rightarrow$ C_3 + γ,… where γ is one or more photons. It was further assumed that the linear C_n chains are destroyed by oxidation reactions until the C_8 chain isomerizes into a ring, which is stable against further oxidation. The C_8 ring (C_8^R) then serves as a seed for grain growth by capture of carbon atoms. Fig. 3 shows the abundance of C_8 rings in the calculations as a function of the declining temperature. Inclusion of the destruction of CO has significantly reduced and delayed the production of C_8 rings.

The reason for the large difference in the abundance of C_8 rings in Runs 1 and 2 is the large difference in CO in the two calculations. In Run 1, CO builds up early. As emphasized in [9], a potentially important pathway to production of linear C_n chains is CO + C$\rightarrow$ C_2 + O. Because CO builds up early in Run 1, this pathway is open. The C_8 ring abundance then builds up rapidly. It levels off at high temperature because the efficiency of CO + C $\rightarrow$ C_2 + O drops, but not before this reaction has allowed the C_8 ring abundance to reach a level of more than 10^{-11} per total number of atoms.

In contrast, in Run 2 the CO abundance is always low. The build up of C_n chains is delayed until the temperature falls below 2000K, at which point the C + C$\rightarrow$ C_2 + γ reaction becomes effective. The abundance of C_8 rings builds to a lower abundance than in Run 1 and certainly persists over a much smaller temperature range.

Our current network does not yet include the build up of larger molecules by capture of C on C_8 ring seeds. We are incorporating this effect using an improved version of the binning employed in [10] that also properly accounts for the time-dependent movement of abundance from one bin to another. In advance of that development, however, we note that an abundance of 10^{-11} for seeds for grain production would lead to graphite grains of roughly 10^{11} atoms or roughly 0.3 microns in size. This is smaller than the largest graphite grains recovered from primitive meteorites (> 1 micron in size).

In Run 2, the final C_8 ring abundance is nearly 30 times smaller than in Run 1. This would lead to grains roughly three times larger in radius. More significantly, we note that, once a supply of C_8 ring seeds builds up, capture on those seeds will be rapid and will compete with further production of seeds. We can thus expect the actual seed abundance may be even smaller than the final 10^{-12} per total number of atoms shown in Fig. 3 and the resulting grains could easily be even larger than a micron in size.

The results in the present work show a higher abundance of C_8 rings than our network calculations appropriate for the oxygen-rich ejecta [2]. This is largely due to the higher abundance of carbon and the lower abundance of oxygen in helium-shell matter. The lower abundance of O, in particular, decreases the oxidation rate for linear chains, which allows for a more rapid build up of C_8. A proper time-dependent treatment of binning will thus be essential to follow the competition between seed build up and depletion of free carbon and the final resulting grain sizes in our calculations of grain production in the helium shell.

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