SOME INVESTIGATIONS ABOUT THE CARSON OPACITIES

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Accurate opacities for stellar composition mixtures are needed for all studies of stellar structure, evolution, stability, and pulsation. In several cases it appears that larger opacities in the range of temperature near one million kelvin would assist is resolving some current discrepancies between observations of stars and some theoretical predictions. Opacities published by Carson, Mayers, and Stibbs (1968) and more recently modified and available informally, have this larger opacity in this temperature region compared to the widely used Los Alamos opacities. See the tables of Cox and Stewart (1965, 1970ab) and Cox and Tabor (1976). It is therefore of great interest to see if the actual cause of the differences between these two sets of opacities can be found and discussed.

Three problem areas where increased opacities would be welcome are: the observed broadening of the upper main sequence that can be produced with larger opacities that tend to expand the stars; the existence of the double-mode Cepheids and their anomalously low period ratios which can be predicted to be lower, as observed, if opacities are larger; and the small sensitivity of the low mass population II horizontal branch luminosity to the metal content of their compositions that would be more effective if their opacity were increased. Several other problems that could be solved by larger opacities have been widely discussed, but we feel that they are not justifiably an opacity problem. The conclusion of our considerations are that the Thomas-Fermi method for getting opacities used by Carson and his collaborators does not produce values appreciably different from those obtained without this method at Los Alamos, and that these persistent astrophysical problems must be solved in other ways. We here propose a possible error in the Carson opacities, and, further, we mention another that seems to be the correct reconciliation between these two opacity sets.

Figure 1 displays the logarithm of the ratio of the Carson to the Los Alamos opacities versus temperature and density for his mixture C312. This mixture has a hydrogen mass fraction X of 0.73, a helium mass

A. Maeder and A. Renzini (eds.), Observational Tests of the Stellar Evolution Theory, 41–46.

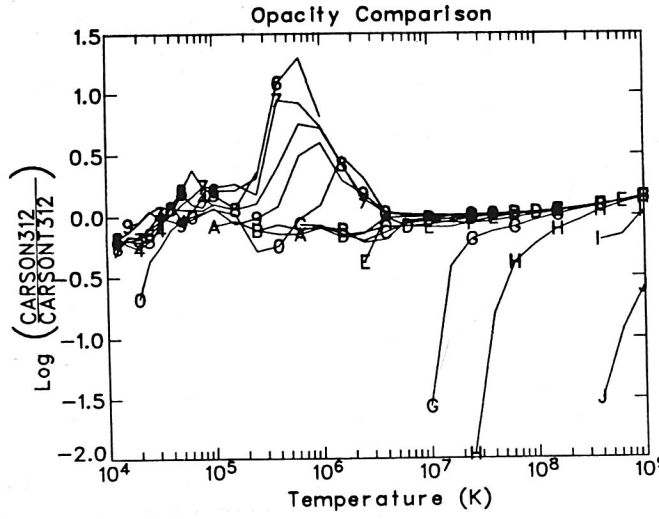

Figure 1. This comparison of the Carson and Los Alamos opacities gives the logarithm of the ratio of the Carson values to the Los Alamos Opacity Library values for integral values of the logarithm of the density from -12 to +7 versus temperature.

fraction Y of 0.25 and the other element mass fraction of 0.02. The points for higher densities (the 0 and the letters) that are significantly below the others are due to the fact that the Carson values include the effects of electron conduction which is not present in the Los Alamos Opacity Library (Huebner et al. 1977) generated table. Differences between the two sets of opacities depend somewhat on density, but mostly they occur in four temperature regions. The Carson opacities are lower in the hydrogen ionization region up to about 30,000 K. The helium second ionization region has higher opacities by up to a factor of two for most densities in stars. The well-known CNO bump where the Carson opacities are ten or more times larger, depending on the density, occurs between 100,000 K and 5,000,000 K. Finally, above 100 million kelvin there is a slow increase of the Carson opacities relative to the Los Alamos ones. We investigate here the last point at one million kelvin on curve 6 which is for a density of 10^{-7}.

A review of the absorption processes that can occur shows that, apart from the dominant electron scattering, the only mechanism that is operating to any noticeable extent here is the bound-free absorption of the CNO elements, especially by oxygen because of its large abundance. This immediately focuses the problem on the Thomas-Fermi method. In this method there is a problem of getting the proper conservation of electrons associated with each atom. The solution for the two quantities, the electron density and the potential distributions, using two equations, the Thomas-Fermi statistics for the electron density and

https://doi.org/10.1017/S0074180900030527 Published online by Cambridge University Press

the Poisson equation for the potential, gives consistent values. However, when the Schrodinger equation is solved using this potential to discretize the energy levels of the bound electrons, the resulting electron numbers and the potential are no longer consistent. An iteration is required to get these values to be the same for both the potential and the energy level solutions. From a discussion by Cloutman (1973), and by inspection of subtle inconsistencies between quantities in Table 3 of Carson, Mayers, and Stibbs (1968), one can see that charge conservation is difficult to get and, further, energy levels can be greatly in error.

Merts in unpublished work has considered the application of the Thomas-Fermi method. He found that when he used the method to get occupation numbers and energy levels for stellar mixtures they differed only a little from those found by the usual Los Alamos methods. Actually, one finds that only K edges seem to contribute significantly to stellar mixture opacities, and the calculations to get their properties are just as accurately done with hydrogenic approximations for the atomic potential. A recent review of possible opacity increases near one million kelvin has been written by Magee, Merts and Huebner (1984).

Figure 2 shows the D versus u diagram used widely for opacity discussions. This comes directly from the current Los Alamos calculations for our one million kelvin and 10^{-7} g/cm^3 point. Here D is proportional to the absorption or scattering cross section multiplied by the cube of u, and u is the photon energy scaled by the temperature in energy units. At the top of the figure is plotted the weighting function that is used to get the Rosseland mean absorption integral. The line marked S is the dominant free electron scattering contribution to the opacity. The steps are the bound free edges for the K and L shells of carbon, nitrogen, and oxygen. Actually the K edge for carbon is at about u=6 and for nitrogen, at about u=8. The very abundant oxygen is not so ionized, and its hydrogen-like and helium-like K edges appear at just over u=10. The very weak K edge for hydrogen like helium with its ionization energy of 54 ev is at u=54/86=0.6. At even lower u one can see the minimum D which is the very small free-free absorption contribution. Some bound-bound (line) absorption in less completely ionized atoms such as neon can be seen at u greater than 10. Here our task is to somehow increase the mean absorption to produce the large Carson value.

This opacity increase can be accomplished either by increasing the numbers of L shell electrons in the CNO elements or by moving the K edges to much lower energies. Here we choose the latter direction, but the most recent work indicates that the L shell occupation numbers are incorrect in the Carson Thomas-Fermi formulation, and they are wrongly overabundant by a huge factor. All K shell energy levels are here divided by 5 to see what effect that will have on the opacities. As one can see, the K edge of oxygen then moves from u=10 to u=2, giving a great contribution to the opacity integral.

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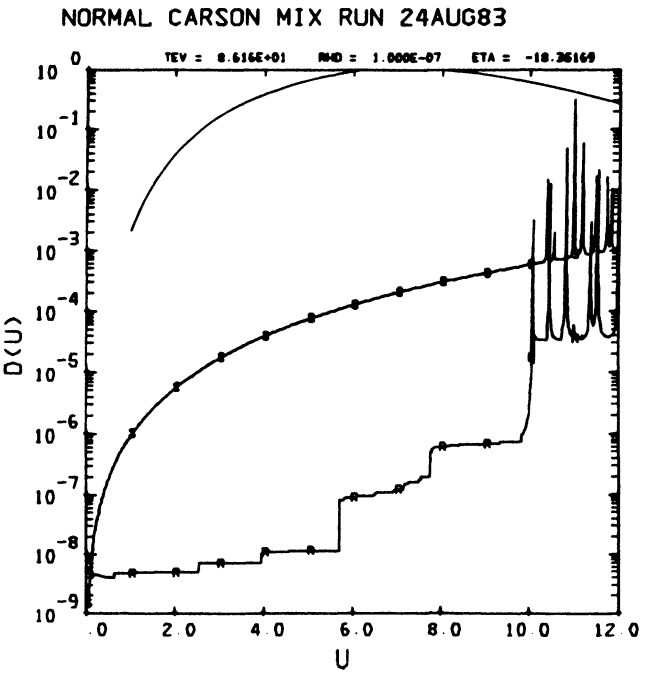

Figure 2. The quantity D, as defined in the text is plotted versus the scaled photon energy for the temperature of one million kelvin (86 ev) and for a density of 10^{-7} g/cm^3. The weighting function, the free electron scattering contribution, and the bound-free absorption edges for the CNO elements are apparent.

Figure 3 shows the Carson opacities for his C312 mixture with three points plotted at 300,000, 500,000, and 1,000,000 K at the density line 6. They track the Carson values well. One further test of this possible error shows, however, that this is not the correct solution for fixing the Carson opacities. At a density of 10^{-4}, a thousand times larger in density, moving the K edges by a factor of 5 gives an opacity of 83 cm^2/g rather than the Carson value of 3.9. This x point is also plotted on Figure 3, but to be a correct fix, it should have fitted along the line labeled 9.

Currently Carson, Huebner, Magee, and Merts at Los Alamos are collaborating to see how the implementing of the Thomas-Fermi method for getting atomic models has been different between the Los Alamos, where no appreciable effect was noticed, and the Carson opacity programs.

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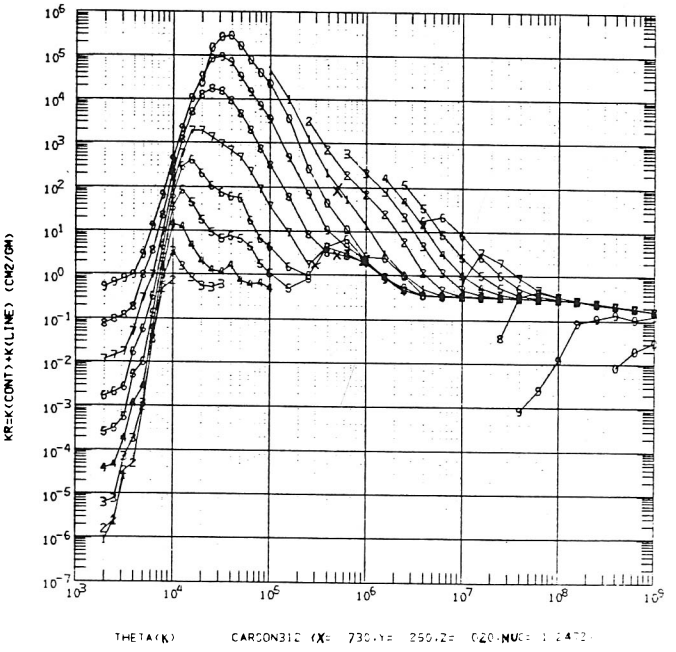

Figure 3. Carson opacities for the C312 mixture are plotted versus temperature for our 20 densities. Three points at 10^{-7} and one at 10^{-4} g/cm^3 are plotted as x points when our proposed fix for the K edge energies is used.

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DISCUSSION

Nissen: Recent abundance analyses of unevolved F-type main-sequence stars show that oxygen is overabundant in metal-poor stars by factors 5 to 10. Do you expect a major change of the opacities computed when such a non-solar oxygen abundance is taken into account?

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Cox: Yes, I do. Such mixtures have been calculated. The effects on evolution tracks may not be very important, however, especially for population II stars. You need to ask people like Renzini, but I believe that higher oxygen is not all that important because Z is so small.

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