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The role of particle diffusion in the lower transition region: revised interpretation of emission measures

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Our new energy-balance models of the lower transition region are shown in the preceding paper (New Models of the Chromosphere and Transition Region). Here we show the influence of particle diffusion on the calculated hydrogen and helium number densities for a given temperature-density model (model C in the preceding paper).

When there are no diffusion or mass-velocity effects, the *local* statistical equilibrium equation for the level-m number density is

$$0 = \sum_{l \neq m} (n_l P_{lm} - n_m P_{ml}), \tag{1}$$

where P_{ij} is the transition rate (s^{-1}) from i to j per particle in the initial state i. When particle velocities are included, this equation becomes

$$\frac{\mathrm{d}}{\mathrm{d}z} [n_m(V_m + U)] = \sum_{l \neq m} (n_l P_{lm} - n_m P_{ml}), \tag{2}$$

where z is geometrical depth, V_m is the diffusion velocity, and U is the fluid or center of mass velocity. V_m has an effect similar to U except that atoms and ions diffuse in opposite directions.

Here we consider only the hydrostatic case with $U = 0$. The diffusion velocity V_m can be calculated from the local temperature and temperature gradient, and the neutral and ion number densities and their gradients.

The derivative term in the statistical equilibrium equation (2) causes the number density at one depth to depend on those at other depths. This is a nonlocal effect that is in addition to nonlocal radiative transfer effects. Both effects combine to modify the ionization of hydrogen and helium.

The proton and neutral hydrogen number densities, n_p and $n_{\mathrm{H\,I}}$, that we calculate for model C are shown in Figure 1 (solid curves) plotted *vs.* temperature. Using the same atmospheric model we have repeated the hydrogen calculations without the effects of diffusion; the results are shown as the dashed lines in the same figure. The effect of diffusion is to substantially increase $n_{\mathrm{H\,I}}$ for $T > 25,000$ K and decrease $n_{\mathrm{H\,I}}$ (while increasing n_p) between 8,000 and 18,000 K.

We have also solved the statistical equilibrium and radiative transfer equations for a 13-level He I atom (22 radiative transitions) and a 6-level He II ion (15 radiative transitions) together with He III. The resulting He I and He II level-1 number densities and He III density are shown as functions of temperature in Figure 2. Diffusion substantially increases $n_{\mathrm{He\,I}}$ for $T > 35,000$ K and decreases $n_{\mathrm{He\,I}}$ (while increasing $n_{\mathrm{He\,II}}$) between 9,000 and 25,000 K. Including the effects of diffusion also increases $n_{\mathrm{He\,III}}$ for $T < 60,000$ K.

We are currently preparing a paper for the Astrophysical Journal that will provide the details of these calculations. The overall results shown here indicate that the nonlocal effects of particle diffusion in the statistical equilibrium equations substantially change the hydrogen and helium number densities in the lower transition region. We plan to carry out the corresponding calculations for heavier elements in the near future.

These results suggest that emission-measure studies of the lower transition region that ignore the nonlocal effects of particle diffusion are likely to be unreliable.

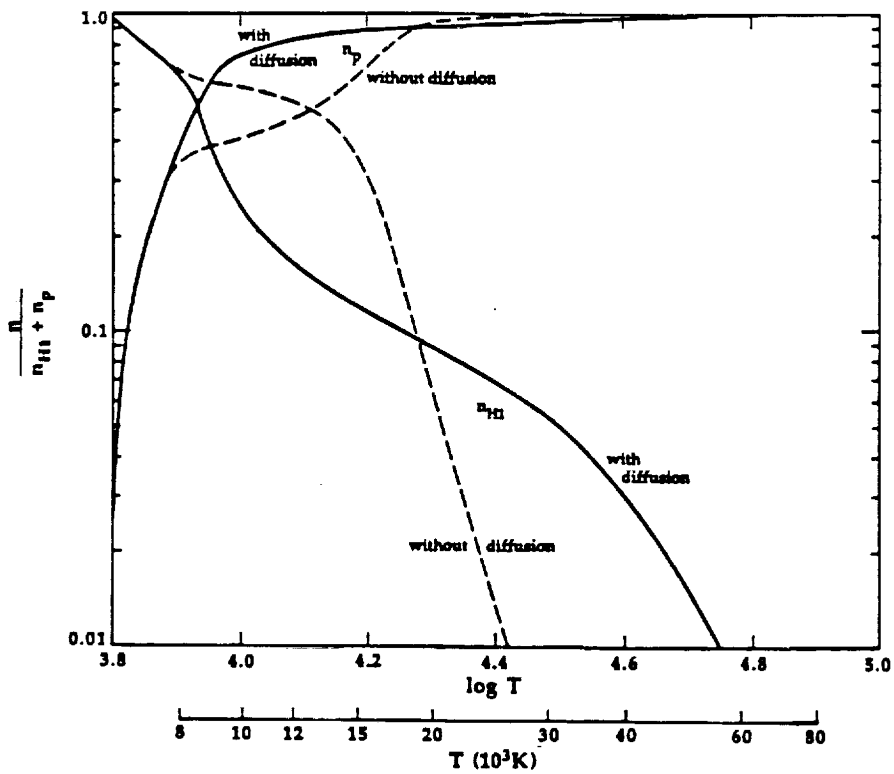

Figure 1. Relative proton and neutral hydrogen number densities *vs.* temperature, with and without the effects of particle diffusion.

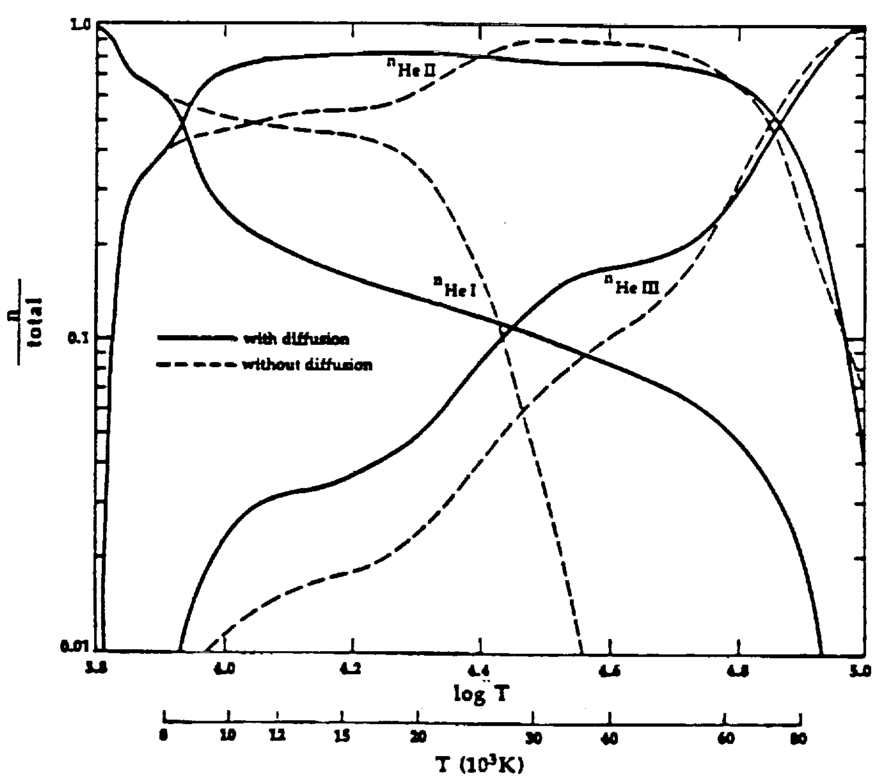

Figure 2. Relative He I, He II, and He III number densities *vs.* temperature, with and without the effects of particle diffusion.