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# The influence of gravitational settling and selective radiative forces in PG 1159 stars. II

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**Abstract.** Previous investigations have shown that time-independent diffusion calculations cannot explain the large abundances of carbon and oxygen in the helium-dominated atmospheres of hot pre-white dwarfs. Therefore we investigate in this paper the time evolution of the chemical composition in the outer regions with surface layer masses $\leq 10^{-8}M_*$. The elements He, C, N, O and Ne are taken into account. It is shown that for $\log g$ = 7.0 and $T_{\rm eff}$ = 140000K and 65000K , respectively, gravitational settling should lead to a strong depletion of both elements within a time-scale of 1000 y. According to theoretical evolutionary tracks for post-AGB stars, PG 1159 stars with $M_* \approx 0.6M_\odot$ should have passed through regions in the HRD with $T_{\rm eff}$ = 140000K and $\log g \approx 6.0$. For these model parameters the radiative forces are strong enough to transform a helium-rich atmosphere with only traces of heavy elements into a metal-rich one. However, this transformation takes about 800000 y, long compared to the corresponding time-scales of stellar evolution. For more massive objects, the observational results cannot be explained by diffusion processes alone.

**Key words:** stars: abundances – stars: evolution – diffusion – white dwarfs

## 1. Introduction

In a recent paper (Unglaub & Bues, 1996; Paper I) we have investigated the influence of gravitational settling and selective radiative forces in PG 1159 stars (for a review about these objects see Werner et al., 1996). The results have shown that under certain circumstances diffusion processes may lead to large abundances of heavy elements in the outer regions with surface mass fractions of about $10^{-8}M_*$. However, radiative levitation and other diffusive processes alone cannot explain the observed abundances in these stars, especially the observed and predicted carbon abundances are in clear disagreement.

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For PG 1159-035 and PG 1520+525, both with $T_{\rm eff}$ = 140000K and $\log g$ = 7.0 the spectroscopic mass determination by theoretical evolutionary tracks yields $M_* \approx 0.6M_\odot$ (Werner et al., 1991). For PG 1159-035, a pulsator, this result has been confirmed by pulsation analysis (Kawaler & Bradley, 1994). According to the corresponding evolutionary track (helium burners, mass loss type B) of Wood & Faulkner (1986) these objects have passed through a region in the HRD where the effective temperature is also 140000 K, but the surface gravity is only $\log g$ = 6.0. For these model parameters, we predicted in Paper I a thin metal-rich region floating ontop of a helium-rich mantle. However, stars with surface gravities significantly lower than $\log g$ = 7.0 cross this region within less than 30000 y. In the present paper a decision will be obtained, if diffusion can transform an originally helium-rich atmosphere with about solar number ratios of the elements C, N, O and Ne into a metal-rich one within this time-scale. If this were possible, diffusion processes could be an explanation of the surface chemistry alternative to the "born-again AGB star" scenario proposed by Werner et al. (1991) and Kawaler & Bradley (1994).

The object H1504+65 with $T_{\rm eff}$ = 170000K, $\log g$ = 8.0 has a spectoscopically determined mass of $0.86M_\odot$ from model atmospheres with carbon and oxygen only (Werner, 1991). According to the evolutionary tracks this star has passed through a region in the HRD with a maximal effective temperature of 350000 K at $\log g$ = 7.2. For these model parameters we predicted in Paper I an atmosphere which consists of heavy elements with no detectable amount of helium, whereas for $T_{\rm eff}$ = 170000K, $\log g$ = 8.0 carbon and oxygen should be trace elements only. Nevertheless diffusion processes could be a possible explanation for the observational results, if the heavy elements were enriched rapidly when the star crossed the ultrahot region, and sank slowly until it has cooled down to $T_{\rm eff}$ = 170000K.

In a direct comparison of theoretical predictions with observational results for objects with $T_{\rm eff}$ = 140000K, $\log g$ = 7.0 and $T_{\rm eff}$ = 65000K, $\log g$ = 7.0 the time-independent calculations predicted surface abundances of carbon and oxygen, which are clearly smaller than the observed ones. These discrepancies may be a consequence of too restrictive assumptions in the diffusion

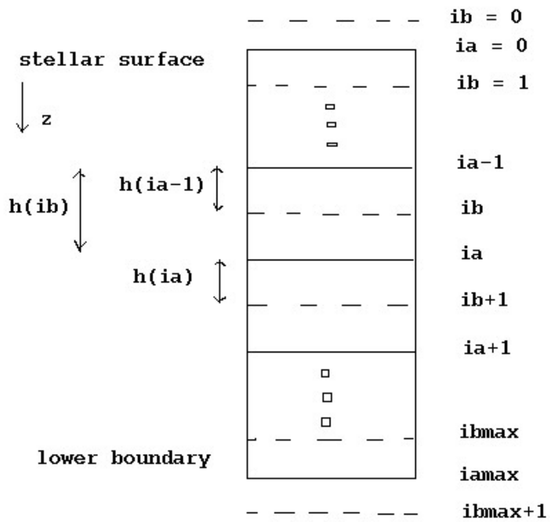


**Fig. 1.** Explanation of the variables used in the text

calculations. For example, the effects of possible hydrodynamical instabilities and mass loss are ignored. In the present paper we investigate another possible reason for the failure of the time-independent calculations to explain the observations: Do the heavy elements not sink, because the diffusion time-scales are long in comparison to the time scales of stellar evolution? This question will be clarified by calculations which start with a chemical composition typical for PG 1159 stars.

Recently Dehner & Kawaler (1995) have computed evolutionary sequences of white dwarf models which include time-dependent gravitational settling. They published results which refer to surface mass fractions between $10^{-8}$ and $10^{-3}$ stellar masses. In deep regions it may indeed be a good approximation to neglect the effect of radiative forces on the composition profile, because the elements helium, carbon and oxygen are almost completely ionized. Our paper, however, deals with the outer regions where the effect of radiative forces has to be taken into account as shown in Paper I and detailed opacity calculations are necessary to give proper attention to the influence of the composition on the radiation flux.

## 2. Physical assumptions

As in Paper I we take into account the elements He, C, N, O and Ne, assuming a plane-parallel, one dimensional stratification. The possible effects of mass-loss or convective mixing, which would lead to more complicated momentum equations, are excluded. In contrast to the calculations of Dehner & Kawaler (1995) the background stellar structure is not allowed to evolve: $T_{\rm eff}$ and log $g$ are held fixed during the diffusion calculations. If the diffusion velocities $w_l$ for each element are small compared to the thermal velocities, the total mass flow is zero and thermal diffusion can be neglected, then the momentum equation for each element can be written according to Burgers (1969):

$$\frac{dp_l}{dz} - n_l m_l g + n_l \overline{Z}_l e E + n_l \overline{F}_{l,\rm rad} = \sum_t K_{l,t} \left( w_t - w_l \right) \quad (1)$$

$n_l$ and $m_l$ are the particle density and mass, respectively. $\overline{Z}_l$ is the mean electric charge of the particles of element $l$, which follows from a solution of the Saha equations as described in Paper I. The mean radiative force $\overline{F}_{l,\rm rad}$ acting on the particles of element $l$ is obtained in the same way as in Paper I. It has been assumed that in photoionization processes the photon momentum is transferred onto the heavy particle alone, so that the selective radiative forces which are due to bound-free transitions are maximized. The $K_{l,t}$ are resistance coefficients which are calculated according to Paquette et al. (1986). The electric field $E$ is obtained from the momentum equation for the electrons (see below). The depth variable $z$ is a length and, in difference to Paper I, increases from the outer boundary towards the stellar interior. As one of these equations is redundant, we replace the momentum equation for helium by the condition of zero mass flow:

$$\sum_l n_l m_l w_l = 0 \quad (2)$$

This set of five linear algebraic equations can be solved for the diffusion velocities of the various elements. In the framework of this theory the particles are assumed as being classical, interacting via Coulomb forces, the possible effects of inelastic and reactive collisions are ignored. Using only one momentum equation for each element, we disregard the fact that the particles in the various ionization states have different diffusion velocities. A consistent treatment of this effect on the chemical statification would require to take into account the momentum exchange between the various ions which is due to photoionization processes and reactive collisions (for a review concerning improvements on diffusion calculations including radiative accelerations see Gonzales et al., 1995 and references therein).

According to Geiss & Bürgi (1986) it is a good approximation to take into account the interaction between free electrons and ions only via the electric field and to neglect the electron collision term. Therefore we assume

$$\frac{dp_{\rm e}}{dz} - n_{\rm e} m_{\rm e} g - n_{\rm e} e E + n_{\rm e} F_{\rm e,rad} = 0 \quad (3)$$

This equation is solved for the electric field and inserted into the Eqs. (1). The radiative transfer equation is solved by use of the diffusion approximation:

$$\frac{dT}{dz} = \frac{3}{16} T_{\rm eff}^4 \overline{\chi} \frac{1}{T^3} \quad (4)$$

where $\overline{\chi}$ is the Rosseland mean opacity in $\rm m^{-1}$, the opacities are computed as described in Paper I.

## 3. Numerical method

To solve the time-dependent diffusion problem an Eulerian differencing scheme is used, which is based on a finite difference approximation for the spatial part of the differential equations.

### 3.1. Spatial part of the equations

To evaluate the finite difference equations we introduce a primary and a secondary grid, designated as a and b, respectively (see Fig. 1). During the computations a fixed gas pressure scale is used. The mesh points of the a-grid are spaced such that the gas pressure $P_{\rm g}$ differs by 7% between two mesh points of the a-grid.

$$P_{\rm g}\,(i{\rm a}+1) = P_{\rm g}\,(i{\rm a}) + 0.07 * P_{\rm g}\,(i{\rm a}) \tag{5}$$

At the outer boundary ($i$a = 0) $P_{\rm g}$ values between 5000 Pa (for the case log g = 6.0) and 120000 Pa are taken. This results in 200 to 270 a-grid points for the various cases considered. For the b-grid with $1 \leq i{\rm b} \leq {\rm ibmax}$ is

$$P_{\rm g}\,(i{\rm b}) = \frac{1}{2} * \left(P_{\rm g}\,(i{\rm a}) + P_{\rm g}\,(i{\rm a}-1)\right) \tag{6}$$

If the chemical composition is known at each gridpoint (we start with constant composition at a time $t$ = 0) Eq. (4) can be integrated from the outer boundary (where $T^4\,(i{\rm a}=0) = \frac{1}{2}T_{\rm eff}^4$ according to the Eddington approximation) towards the stellar interior by use of a midpoint method, so that

$$T\,(i{\rm b}) = T\,(i{\rm a}-1) + \frac{dT}{dz}\,(i{\rm a}-1) * h\,(i{\rm a}-1)\,;$$
$$h\,(i{\rm a}-1) = \frac{P_{\rm g}\,(i{\rm b}) - P_{\rm g}\,(i{\rm a}-1)}{\rho\,(i{\rm a}-1)\,g - n\,(i{\rm a}-1)\,\overline{F}_{\rm rad}\,(i{\rm a}-1)} \tag{7}$$

and

$$T\,(i{\rm a}) = T\,(i{\rm a}-1) + \frac{dT}{dz}\,(i{\rm b}) * h\,(i{\rm b})\,;$$
$$h\,(i{\rm b}) = \frac{P_{\rm g}\,(i{\rm a}) - P_{\rm g}\,(i{\rm a}-1)}{\rho\,(i{\rm b})\,g - n\,(i{\rm b})\,\overline{F}_{\rm rad}\,(i{\rm b})} \tag{8}$$

$n\overline{F}_{\rm rad}$ is the total momentum per unit volume and time which is transferred from photons to matter. At each mesh point of the a- and b-grid the Saha equations are solved and opacities and radiative forces are calculated.

Now the left hand sides of Eqs. (1) as well as the $K_{l,t}$ are evaluated at the mesh points of the b-grid with $1 \leq i{\rm b} \leq {\rm ibmax}$, where the gradients of the partial pressures are represented by $\left(p_l\,(i{\rm a}) - p_l\,(i{\rm a}-1)\right)/h\,(i{\rm b})$. If the left hand sides of Eq.(1) for the various elements are summed up the result must be zero because of momentum conservation. The numerical method as described in Eqs. (7) and (8) guarantees that this sum is exactly zero also for the equations in their discretisized form. This is important because test calculations for mixtures with helium and carbon only have shown that deviations from zero may lead to wrong diffusion velocities, if one of elements has a very low abundance. The system of Eqs. (1) and (2) is solved for the diffusion flow $j_l = n_l m_l w_l$ of each element. The boundary conditions are such that the diffusion flows are zero at the outer boundary

$$j_l\,(i{\rm b}=0) = 0 \tag{9}$$

and the chemical composition remains constant at the lower boundary

$$j_l\,(i{\rm bmax}+1) = j_l\,(i{\rm bmax}) \tag{10}$$

Now the gradients of the diffusion flows at each mesh point of the a-grid are obtained by

$$\frac{dj_l}{dz}\,(i{\rm a}) = \frac{j_l\,(i{\rm b}+1) - j_l\,(i{\rm b})}{h\,(i{\rm a}) + (h\,(i{\rm b}) - h\,(i{\rm a}-1))} \tag{11}$$

Note that the mesh-points of the b-grid are not exactly centered in space.

### 3.2. Time integration

In this subsection all quantities refer to the a-grid. The chemical composition is specified by the ratios of the number density of each element $l$ relative to helium

$$\epsilon_l = \frac{n_l}{n_{\rm He}} \tag{12}$$

From the equation of continuity $dn_l/dt + dj_l/dz = 0$

$$\frac{d\epsilon_l}{dt} = \epsilon_l \left(\frac{1}{n_{\rm He}}\frac{dj_{\rm He}}{dz} - \frac{1}{n_l}\frac{dj_l}{dz}\right) \tag{13}$$

is derived. The composition at a timestep $t+1$ is obtained from the $\epsilon_l$ at time $t$ by

$$\epsilon_l\,(t+1) = \epsilon_l\,(t) + \frac{d\epsilon_l}{dt}\,(t)\,\Delta t \tag{14}$$

The stepwidth $\Delta t$ is such that during one timestep $\epsilon_l$ does not change by more than one percent at any mesh point.

$$\Delta t = \min\left(0.01 * |\epsilon_l \left(\frac{d\epsilon_l}{dt}\right)^{-1}|\right) \tag{15}$$

After each timestep a new model is constructed by integration of the Eqs. (7) and (8). However, the opacities and the radiative forces per particle $F_{l,\rm rad}$ are updated only if the $\epsilon_l$ of one of the elements has changed by at least 5% in at least one of the volume elements. During the first timesteps $\Delta t$ steadily increases from a few weeks to not more than a few years. After some hundreds of years the outermost regions are already very close to a diffusive equilibrium state, because the diffusion time scales are much shorter there than in the inner regions. Then, however, the stepwidth scarcely increases any more. Although the diffusion flows have decreased by a factor of 100 to 1000 in the outermost volume elements, because of numerical reasons they do not vanish. This effect leads to oscillations of the $\epsilon_l$ around their equilibrium value and restricts the stepwidth according to Eq.

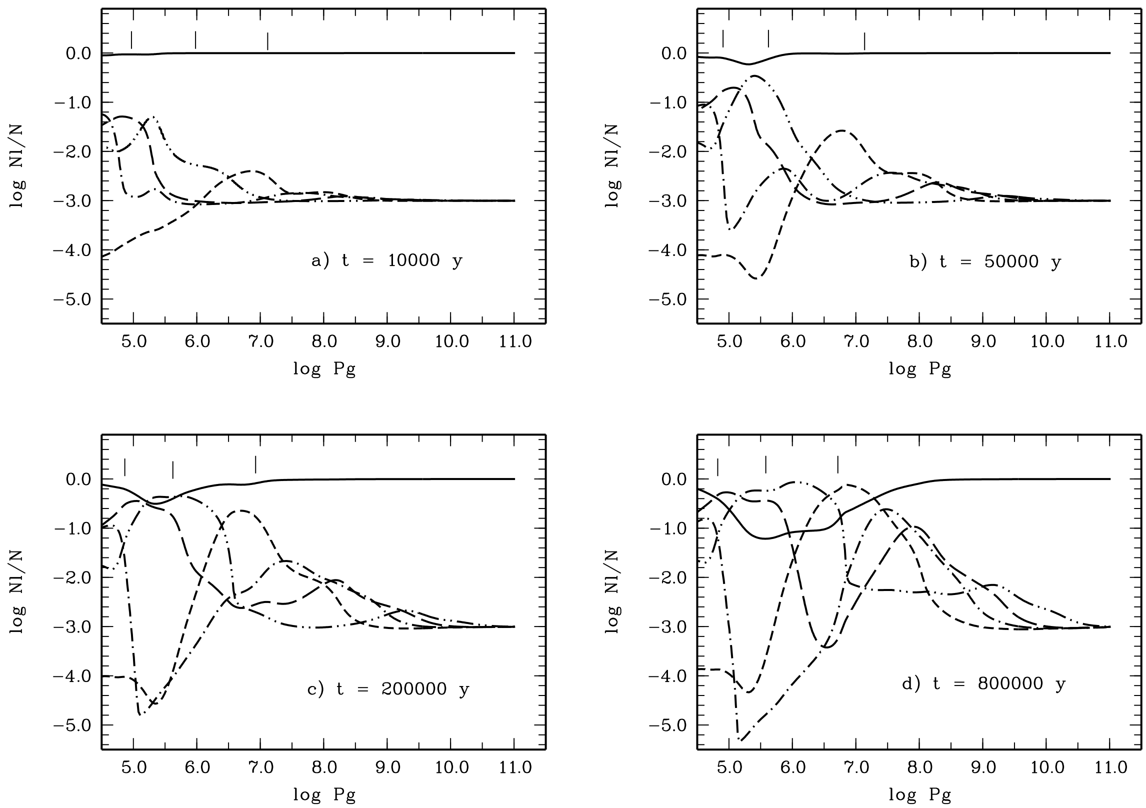


**Fig. 2a–d.** Number fractions of the elements He (full drawn line), C (- - - -), N (- · - · -), O (— — — —), Ne (- ·· - ·· -) as a function of the gas pressure for $T_{\rm eff}$ = 140000K, log $g$ = 6.0 after various times. The number fractions are on a logarithmic scale and are defined as the ratio of all particles of an element to all heavy particles. The gas pressure is in SI-units! The three tick marks in the upper part of each figure show where the Rosseland mean optical depth is $\overline{\tau}$ = 1, 10, 100, respectively.

(15). The stepwidth cannot be increased significantly by use of a factor of e.g. 0.1 instead of 0.01 in Eq. (15). This would only increase the amplitude of the oscillations. The mean change of the composition in these volume elements during several timesteps, however, is almost zero. Therefore it is not necessary to carry out the time consuming calculations of the opacities and the $F_{l,\rm rad}$ after each timestep. However, the computation is still as large that the method cannot be recommended for implementation into stellar evolution codes.

## 4. Results

Fig. 2 shows the results for $T_{\rm eff}$ = 140000K, $\log g$ = 6.0. At a time $t$ = 0 we assume number fractions C/He=N/He/=O/He=Ne/He=$10^{-3}$ for all heavy elements. The lower boundary condition is such that the compositition remains constant there, so that for long times the abundance distribution should converge to the stationary case, for which we predicted an atmosphere dominated by heavy elements with traces of helium only (see Fig. 4a in Paper I). After 10000 y the atmosphere is still far from a stationarity as can be seen from Fig. 2a. This time is comparable to the time scales of stellar evolution of post-AGB stars in the corresponding region of the HRD (according the evolutionary track in Fig. 1d of Wood & Faulkner, 1986, for $M_*$ = 0.6$M_\odot$). Thus it becomes clear immediately that the transformation of a helium-rich into a metal-rich atmosphere is not possible in times which are short in comparison to the time scales of stellar evolution. The number fraction of carbon is still below $10^{-2}$ everywhere in the atmosphere. However, the number fraction of oxygen in the outer regions near $\overline{\tau}$ = 1 is 0.05, which is only slightly lower than the typical oxygen abundance of PG 1159 stars. Although the influence of stellar evolution cannot be neglected for longer times, for this example we proceed with the calculations until the atmosphere is transformed into a metal-rich one. After 50000 y maximal number fractions of oxygen and neon of 0.2 and 0.3, respectively, are obtained in a region with $1 < \overline{\tau} < 10$ (Fig. 2a). After 200000 y (Fig. 2c) neon becomes more abundant than helium near $\overline{\tau}$ = 10. The carbon number fraction has a maximum value of 0.23 at $\log P_{\rm g}$ = 6.7 (the temperature there is 380000 K). Only in this part of the atmosphere where the state of ionization changes from $C^{4+}$ to $C^{5+}$ a carbon enrichment by radiative forces is possible. It takes longer than 200000 y until a carbon abundance typical for PG 1159 stars is possible. After this time, however, the star should already have cooled down to effective temperatures below 100000 K. Therefore it seems to be impossible to explain the observed number ratios of carbon by diffusion, at least if we start from approximately solar number fractions. Af-

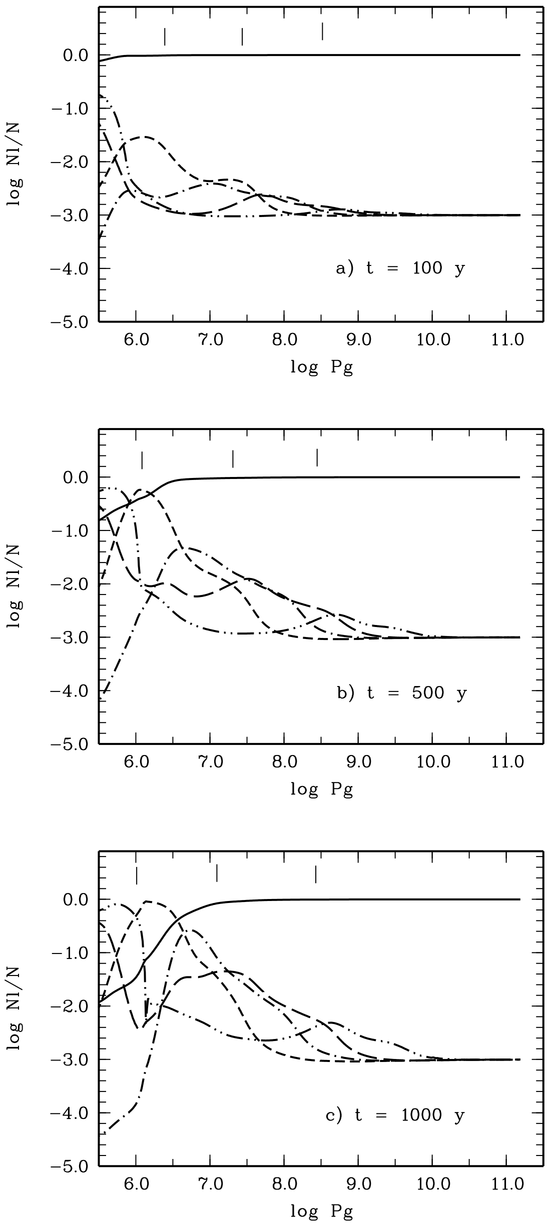


**Fig. 3a–c.** Results for $T_{\rm eff}$ = 350000K, $\log g$ = 7.2 (for explanations see Fig. 2)

ter 800000 y (Fig. 2c) we expect a thin metal-rich region of about $10^{-10}$M$_*$ floating ontop of the helium-rich mantle. A comparison with Fig. 4a of Paper I shows that stationary conditions are still not possible. Only in the outer regions with $\overline{\tau} < 100$ the number fractions of carbon, oxygen and neon are close to their stationary value. The nitrogen abundance has a sharp minimum near $\log P_{\rm g}$ = 5.1. The rapidly increasing radiative forces lead to an increasing diffusion flow of nitrogen in outward direction, which in turn leads to a depletion of the region between the two abundance maxima. At $\log P_{\rm g}$ = 5.1 nitrogen diffuses still outwards with a high diffusion velocity of $5 * 10^{-6}$ m/s. The diffusion velocities of the elements C, O and Ne are lower by about four orders of magnitude. The number fraction of helium is still much larger than predicted for the stationary cases. It still diffuses inwards with a diffusion velocity of about $10^{-8}$ m/s.

Fig. 3 shows the results for $T_{\rm eff}$ = 350000K, $\log g$ = 7.2, again with C/He=N/He=O/He=Ne/He=$10^{-3}$ at time $t$ = 0. After 100 y (Fig. 3a) the atmosphere is still helium-rich. After 500 y (Fig. 3b) carbon and neon are more abundant than helium near $\overline{\tau}$ = 1 and smaller optical depths. According to the evolutionary track of a 0.89 M$_\odot$ post-AGB remnant of Wood & Faulkner (1986) this time is in the same order of magnitude similar as the time scales of stellar evolution. So we see that a transformation from a helium-rich into a metal-rich atmosphere is indeed possible in this case, at least if there is no mass-loss. After 1000 y (Fig. 3b) the helium number fraction in the photosphere has dropped below 0.1 and carbon and neon are the most abundant elements. A comparison with Fig. 7a of Paper I shows that the atmosphere is still far away from a diffusive equilibrium state. Here again time-independent calculations are inadequate.

In Figs. 4 and 5 we take number ratios typical for PG 1159 stars at time $t$ = 0: C/He=0.5 and O/He=0.1. Furthermore is assumed N/He=$10^{-3}$ and Ne/He=$10^{-2}$. Two cases are considered, both with gravities $\log g$ = 7.0: $T_{\rm eff}$ = 140000K (Fig. 4) and $T_{\rm eff}$ = 65000K (Fig. 5). In Paper I surface abundances of carbon and oxygen were predicted which are clearly lower than the observed ones. Therefore it is an interesting question if these discrepancies are simply due to long diffusion time scales or not. A look at Figs. 4 and 5 reveals that in both cases carbon as well as oxygen should sink in time scales which are clearly short compared to these of stellar evolution.

For $T_{\rm eff}$ = 140000K, carbon is significantly depleted already after 100 y in the outermost regions near $\overline{\tau}$ = 1. Its number fraction has decreased by about a factor of three. After 1000 y (Fig. 4b) carbon is a trace element in regions with $\overline{\tau} < 10$. At $\overline{\tau}$ = 1 all number fractions are already very close to the values which have been predicted in Paper I for the stationary case. The calculations have been continued until $t$ = 30000y (Fig. 4c). It is remakable that the depletion of carbon goes on only slowly. This is due to the radiative forces acting in regions where carbon is mainly $C^{5+}$. In depths with $\overline{\tau} > 100$ almost the original abundance is maintained. The carbon-depleted region comprises a surface layer mass of not more than $10^{-11}$M$_*$. The number fraction of oxygen has a maximum value of 0.10 near $\log P_{\rm g}$ = 9.2 (the temperature there is $1.0 * 10^6$K). Therefore in this region it has slightly increased in time (original number fraction at $t$=0: 0.062), which is also due to the effective radiative forces in regions where oxygen has hydrogen-like configuration.

For $T_{\rm eff}$ = 65000K the depletion of carbon and oxygen proceeds still more quickly. After 100 y (Fig. 5a), all number fractions in the photosphere near $\overline{\tau}$ = 1 are below $10^{-2}$, after 1000 y (Fig. 5b) they have reached their value which has been predicted for the stationary case. The dramatic decrease of the neon abundance in the outermost regions is not realistic. This is because we have entirely neglected the radiative forces for $Ne^{3+}$ and states of lower ionization. In Paper I the contribution of the bound-bound transitions of $Ne^{3+}$ has been taken into account, therefore the predictions there are more accurate for this case. After $t$ = 30000y a strong depletion of heavy elements is pre-

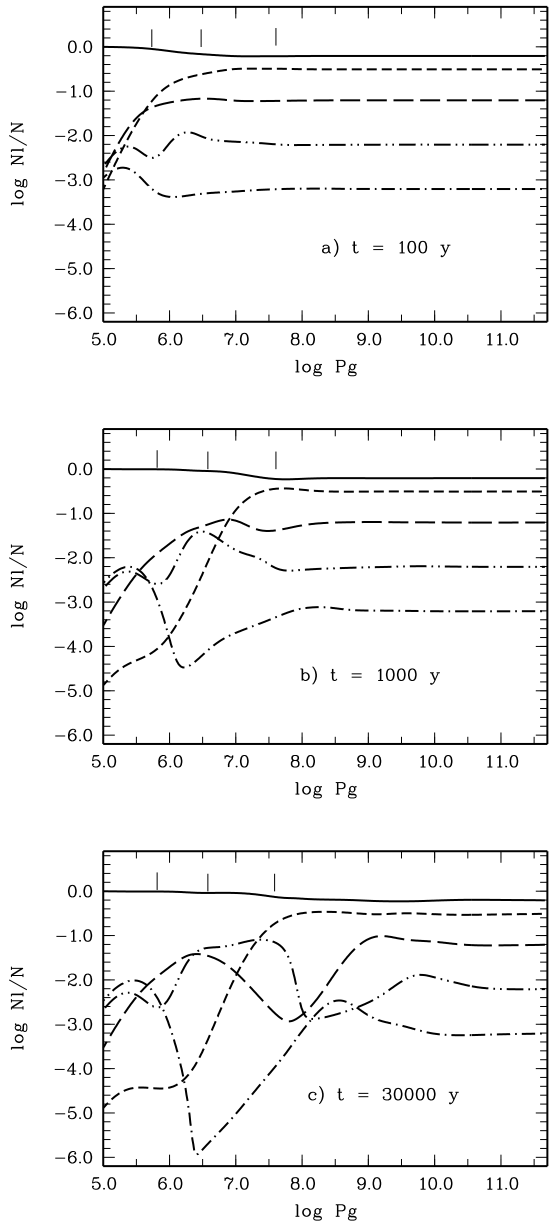


**Fig. 4a–c.** Results for $T_{\rm eff}$ = 140000K, $\log g$ = 7.0 (for explanatior see Fig. 2)

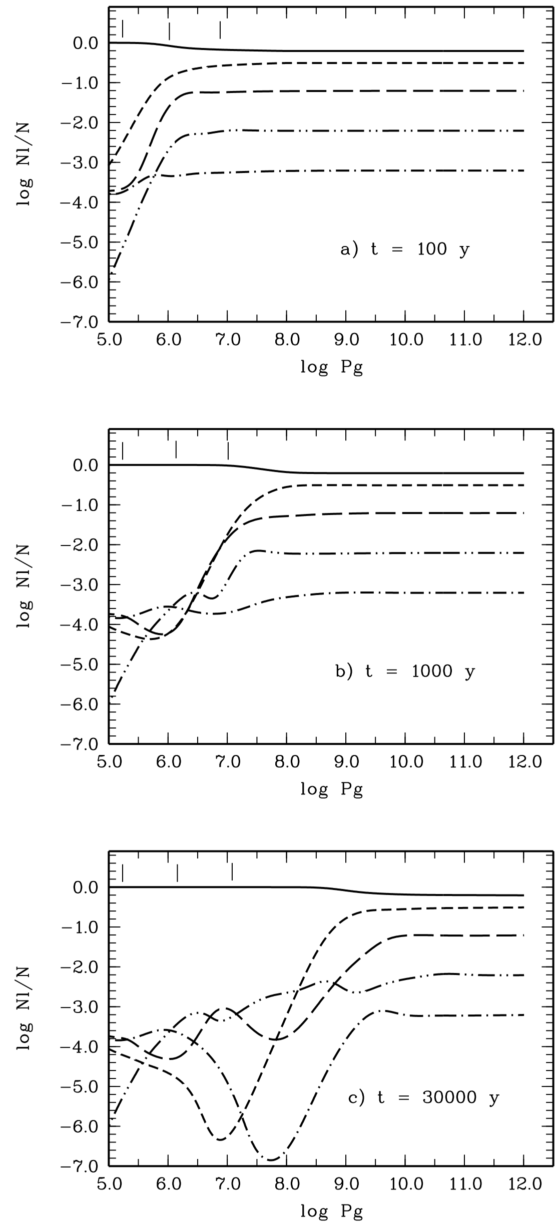


**Fig. 5a–c.** Results for $T_{\rm eff}$ = 65000K, $\log g$ = 7.0 (for explanations see Fig. 2)

dicted in the outer region, which comprises a surface layer mass of about $10^{-10}M_*$ (at $\log P_{\rm g}$ = 9.0). For comparison, Dreizler et al. (1994) obtain from the model atmosphere analysis of HS 0704+6153 number ratios C/He = 0.2, O/He $\approx$ 0.05. Also in the inner regions carbon and oxygen tend to sink. Only near $\log P_{\rm g}$ = 10.25 the oxygen abundance is still the original one (more exactly: it has increased by 0.8%). The temperature in this depth is $1.0 * 10^6$K.

## 5. Conclusions

According to the results of Paper I it seemed possible that originally helium-rich atmospheres of post-AGB stars are transformed into metal-rich ones by diffusion. However, the present results show for $T_{\rm eff}$ = 140000K, $\log g$ = 6.0 that such a transformation takes about 800000 y. According to the post-AGB evolutionary tracks of Wood & Faulkner (1986) this exceeds the time-scales of stellar evolution by about a factor of 20. Whereas a significant oxygen enrichment up to a number fraction of 0.05, at maximum, is possible after 10000 y, the results for carbon are negative. In addition to the results shown in Fig. 2 we have done one calculation with an initial number ratio C/He of $10^{-2}$ instead of $10^{-3}$. But even then only maximal carbon number fraction of 0.07 is reached after 50000 y in regions deep below the photosphere. Therefore, concerning the carbon enrichment in the stellar envelope, the "born-again AGB star" evolutionary scenario seems to be more promising, which results in a carbon mass fraction of more than 10% (Iben & Mc Donald, 1995).

For $T_{\rm eff}$ = 350000K and $\log g$ = 7.2, after 1000 y the present results predict a thin outer layer with about $2 * 10^{-13}$M$_*$ where carbon and neon are more abundant than helium. According to the evolutionary track of Wood and Faulkner (1986), a $0.89 M_\odot$ post-AGB does not stay for more than 1000 y in this ultrahot region of the HRD, where the radiative forces acting on the heavy elements are extremely effective. After about 10000 y the star should have cooled down to $T_{\rm eff}$ = 170000K, $\log g$ = 8.0, which are the model parameters of the object H1504+65. As additional calculations have shown, for these values of $T_{\rm eff}$ and $\log g$ the thin metal-rich layer sinks back within less than 100 y. Therefore also for this case a pure diffusion scenario can be ruled out.

A comparison of the predictions of diffusion theory with observational results for cases with $\log g$ = 7.0 and $T_{\rm eff}$ = 140000K and 65000K, respectively, leads to strong discrepancies in surface layer regions with masses $< 10^{-10}$M$_*$. This affects the carbon number fraction severily, which is predicted too low by three orders of magnitude. The results show that this contradiction cannot be solved by the assumption of long diffusion timescales. Near the photosphere the abundances relaxe to their values obtained from time-independent calculations within 1000 y. In deeper regions, where carbon and oxygen have hydrogen-like configuration, it seems that even large abundances can be levitated by radiative forces. However, diffusion takes place so slowly there that the diffusion theory has to be implemented into a stellar evolution code to obtain reliable predictions. Because other diffusion calculations with different physical assumptions (Chayer et al., 1995) also fail to predict the surface composition deduced from observations, it is necessary to investigate the effect of additional physical processes like convective mixing or mass loss. Whereas convective mixing tends to smear out composition gradients, the effect of mass loss seems to be not clear. It depends on the question which elements or ions are blown away preferably. In order to settle this question, a detailed investigation of the mechanism of momentum transfer via Coulomb collisions between the various ions would be required. According to Springmann & Pauldrach (1992) the usual assumption of regarding radiatively driven winds of hot stars as a simple one-component fluid is not always justified, especially in the case of thin winds with low mass loss rates and high final velocities.

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