CONCLUDING REMARKS (I)

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After a week of highly interesting discussions on 'stellar evolution and the photospheric abundance connection' we now come to resume the contributions to this Symposium. This task has been divided up among three of us, arranged according to the course of stellar evolution, and in alphabetical order of the speakers (*Baschek, Lambert, van Horn*). I begin with the essentially *unevolved stars*, recalling some results and problems, not systematically but rather selected from my own interests.

First I should like to briefly reconsider the accuracy of abundance determinations in view of the contributions following my review. Then some comments on stellar models are given, followed by a few remarks about peculiar A stars. Finally, the similarity of the oxygen abundance in Magellanic Cloud B stars and galactic population II stars is pointed out.

1. On the accuracy of element abundances

In general, the abundances derived from stellar spectra have errors (including systematic errors of about $\pm0.2\ldots\pm0.3$ dex, even for analyses from spectra of relatively high S/N. In particularly favourable cases, however, higher accuracy (≤ 0.1 dex) can be achieved. On the other hand for many interesting stellar groups only an accuracy worse than 0.3 dex can be obtained (*Baschek*). The presentations on this Symposium further substantiated this and supplemented further examples, e.g. on the one side helium can be determined quite accurately in hot stars (*Hunger*), on the other side not very high accuracies hold for Tc in S stars (*Kipper*), [Fe/H] in metal-poor stars (*Luck*), the abundances of the central stars of planetary nebulae (*Mendez*) and of the Wolf-Rayet stars (*Willis, Nugis*).

G. Michaud and A. Tutukov (eds.), Evolution of Stars: The Photospheric Abundance Connection, 447–450.

2. Stars around the main sequence

Impressive results have been reported on abundance determinations as well as on theoretical calculations taking into account diffusion, mixing processes etc. This work has largely been motivated by the need of interpreting the lithium problem and the variety of Ap stars. 'Conventional' calculations of stellar evolution have been extended by considering a variety of physical processes such as (semi) convection, meridional circulation, shear mixing, tidal mixing, diffusion, overshooting, mass loss, turbulence, gravity-wave mixing, light-induced drift etc. The goal is to construct *self-consistent* models, i.e. models with *no* free parameters in which some of these processes necessarily have to be included — "Diffusion cannot be avoided" (*Michaud*). Other processes are relevant only in some stars, e.g. only in (rapidly) rotating stars. Let us sketch the steps on the way toward a self-consistent evolutionary model of the entire star, i.e. of the interior plus the atmosphere:

First, a model of a *non-rotating, non-magnetic, single* star should include diffusion, stellar wind and mass loss, and gravity waves in addition to the standard physics. In this case not only the stellar mass and the composition at birth determine the stellar structure, but also *time-scales* characteristic of these processes enter the problem. While the position and track in the Hertzsprung-Russell diagram are essentially determined by the time-scales of the nuclear processes such as hydrogen or helium burning, the additional parameters may lead to different observable abundances in the atmospheres of stars which are located essentially at the same place in the HRD.

The next step is a *rotating*, non-magnetic single star in which meridional circulation and other rotation-induced processes occur. The additional parameter required to describe this case is the angular velocity $\Omega(\mathbf{r}, t_0)$ for each position $\mathbf{r}$ in the star at a starting time t_0 of the model calculation. Then with the appropriate boundary conditions, in principle, the transport of angular momentum and hence the redistribution of Ω is determined. — Several processes relevant to surface abundance changes depend on $\Omega(r)$ rather than on the 'rotational velocity' Ω alone (*Hunger*). This requires a thorough definition of observed and calculated (average) surface abundances.

At this step we might note that the modelling described so far is already complicated, but it is only comparable with the task of predicting the weather on Earth!

For a *rotating, magnetic* single star the magnetic field configuration $\mathbf{B}(r, t_0)$ at t_0 enters as a further parameter set, determining together with the boundary conditions the evolution of $\mathbf{B}$ in principle. Depending on its strength, the magnetic field may only modulate the hydrodynamic processes or may dominate them. Polar caps, 'abundance spots' etc. may result in the latter case. — Obviously, a *close companion* will complicate things even more.

How far advanced are we now with the modelling of these grand scenarios of self-consistent models? My impression from this Symposium is that substantial progress has been made dealing with the first and second step. But even for the case of a non-rotating star unsolved problems remain, in particular if we move from the main sequence to evolved stars. This has been illustrated by several review speakers who pointed out the necessity of *'additional' mixing* mechanisms in order to interpret the observed abundances (*Lyubimkov, Tutukov, Sneden, ...*).

After the discussion of some theoretical aspects we turn to the question of how many *observational* parameters are needed to account for the variety of stars (near the main sequence). Is it one for each group of peculiarity or peculiarity phenomenon such as silicon stars, Am/Fm stars, ...? But how can we describe the diversity of the abundance patterns *within* each of these groups and how the many superficially normal stars (*Cowley*)? We need a model sufficiently flexible to define specific groups on the one hand and to allow for individual variations on the other. The situation is reminiscent of that for biological *species* on the one side and *individuals* on the other. Since stochastic elements play a role in living organisms as well, this analogue may lead to provocative questions: How well do we understand the mathematical character of the complex system of equations describing stellar structure and evolution? How is the behaviour of the coupled equations of internal/atmospheric structure, radiative transport, particle transport (diffusion), turbulence etc.? Could we even speculate that all the various observed abundance patterns arise as *chaotic* solutions?

3. On peculiar A stars

Out of the wealth of results presented on peculiar A star, only two aspects are picked out here. The abundance patterns and other properties of the *Ap stars* have been described in great detail (*Cayrel, Takada-Hidai, Ryabchikova, Landstreet, Cowley*). Within the theoretical frame for their interpretation (*Sakhibullin, Demarque, Michaud*) there is agreement that the anomalous abundances are basically due to diffusion processes. No signature for a nuclear origin of at least some anomalies seems to be discernible.

The peculiar abundance patterns of the *λ Boo stars* (*Baschek, Cowley*) seems to require an interpretation different from that of the main types of Ap stars. Recently Venn and Lambert (1990, preprint) suggested an origin by separation of the interstellar or circumstellar gas from dust grains. However, not all of the spectral properties of the λ Boo stars are really understood, e.g. the feature at λ 1600 Å. The role of differential non-LTE effects due to the different ultraviolet continua of the weak-lined λ Boo stars compared to the standards has yet to be explored. Incidentically, an analogous effect seems to hold in the metal-poor solar-like subdwarfs leading to an overionisation of iron (poster: *Bikmaev* et al.). A further interesting question is whether *evolved* λ Boo stars exist (poster: *Corbally* and *Gray*).

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4. The oxygen abundance in young and old stars

In our Galaxy the stellar abundance of oxygen relative to iron, [O/Fe], increases with decreasing [Fe/H] or with increasing age of the stars. For [Fe/H] $\simeq -1.0$ the increase is about 0.5 dex (*Truran*). This value is strikingly similar to that in objects of a completely different history of chemical evolution, the essentially unevolved B stars and the H II regions in the Magellanic Clouds, irregular galaxies very different from the Galaxy. Recent work of our Heidelberg group (references cf. *Baschek*) of three B stars, members of blue globular clusters in the Magellanic Clouds (NGC 1818/ D12 and NGC 2004/ B15 in LMC, NGC 300/3 in SMC), shows that all these stars — with masses around 15 $M_{\odot}$ — have an oxygen excess of $\simeq +0.5$ dex while their metal deficiencies are in the range between -0.7 and -1.0. The abundances of C, O, and S are as in the H II regions, whereas N is in excess. This probably indicates some 'additional' mixing since from their positions in the HRD no products of nuclear burning are expected at their surfaces (cf. *Maeder*). An enrichment of N due to rotational mixing is unlikely since $v \sin i \leq 45$ km s^{-1}. The common value of [O/Fe] in young metal-poor B stars and in old metal-poor population II stars may be relevant for the modelling of the chemical evolution of spiral and irregular galaxies.

I hope that my remarks will stimulate an intense and fruitful discussion before we continue with the résumés of the advanced phases of stellar evolution.

References

Names given in *italics* refer to review papers and posters presented at this Symposium.