mass-ratio cannot be less than about 7·1. That is, only a small component need or can be ejected. Equality of masses of the two pieces is quite impossible. (This by the way is yet another argument against the fission theory, since if we assume stable binary orbits the least mass-ratio possible is about 3:1, and so close binaries of equal masses, which are common enough, could not be explained by fission. If loss of mass by radiation is invoked to equalize the masses, the orbit evolves and the system is no longer a close one.)

Given every factor in its favour, the theoretical considerations on which the fission hypothesis has been based are found in fact to be against the process on every count. This conclusion ignores the question whether actual stars are sufficiently closely representable by the assumption of uniform density. Of course we are now pretty certain that they depart very much from this. It ignores the criticism that evolution by gradually increasing density has no real valid basis in the theory of the structure and development of ordinary stars, and it ignores the question whether stars are in fact created as single massive stars already endowed with large angular momentum.

To sum up, *Jeans's main errors* in his theory of fission were as follows:

(1) In believing that secular instability invariably sets in before ordinary instability, and hence that any question of ordinary instability was irrelevant.

(2) In misunderstanding his own result that the system was secularly unstable, and reaching exactly the same conclusions as he had reached when he believed he had proved it was secularly stable.

(3) In supposing that evolution would take place along the pear-shaped series. This would require angular momentum to be subtracted from the system, whereas once the gradual increase of angular momentum has brought the system to an unstable state the subsequent motion is with constant angular momentum. The parameter defining the series is not to be regarded as a dynamical co-ordinate.

(4) In supposing circular orbits could result. (He actually states at one point that the masses must be projected away from each other, but then goes on to invoke collisions to round up the orbits. This in any case is ruled out by the fact that a stable binary system has a finite separation between its components.)

(5) In supposing that equal components could result. The simplest considerations of energy and angular momentum show this to be impossible.

Discussion du rapport de LYTTLETON

Martynov demande quel changement subissent les conclusions de Lyttleton pour les étoiles possédant une concentration de matière.

Lyttleton pense que la situation est pire et la fission impossible.

7. THE CHEMICAL COMPOSITION OF THE STARS AND ITS RELATION TO STELLAR EVOLUTION

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On the one hand the rate at which stellar evolution progresses will depend on the chemical composition of the star. On the other, as a by-product of the nuclear processes involved in the energy production, the chemical composition of the reacting material will change. Stellar models can be used to provide information as to the composition of the reacting zones, stellar spectroscopy will provide the composition of the atmospheres, and of those zones of the stellar envelope which have been well mixed with the atmosphere by convection and circulation currents.

Before one can interpret the chemical abundances indicated by spectroscopic observations of stellar atmospheres, the question arises how far a star is chemically well mixed. Evidence has been accumulating recently indicating that in the sun the mixing is very slow and that the atmospheric abundance has been unaffected by nuclear reactions. The most reliable laboratory nuclear cross-sections predict a ratio of C^{12}/C^{13} of about 4/1 for an equilibrium mixture in which the C–N cycle is at work. This ratio does not hold for the solar atmosphere, in which $C^{12}/C^{13} > 40$ (Schwarzschild, Richardson, Greenstein). Furthermore, the solar atmosphere has appreciable concentrations of lithium and beryllium (Greenstein) both of which would be rapidly destroyed at temperatures above four million degrees. On the other hand, the majority of the carbon stars show (McKellar) the predicted carbon cycle ratio of C^{12}/C^{13}, indicating that mixing has occurred. Furthermore, the Sun is deficient in lithium relative to the Earth, indicating some mixing. An extra parameter, such as the speed of rotation, may be involved. In any case, the surface composition can only be taken as indicative of internal composition, not as identical to it.

The primary effects of nuclear processes are: (*a*) transmutation of H into He and (*b*) transmutation of He into C.

(*a*) $H \rightarrow He^4$. Depletion of the hydrogen either by the proton-proton or by the C–N process can be appreciable only for the brighter stars, and among those only for the older ones. Furthermore, for spectroscopic detection, the mixing must be good. It is nevertheless extraordinary how rare observational examples are. If we omit the carbon stars, the only known objects are *υ* Sgr, HD 30353 (supergiants), and HD 124448, HD 160641 (main sequence). The rarity of these stars is striking. For example, many thousands of high luminosity O, B and supergiant stars are now known, with very short life expectancy. The nature of the end products of similar objects existing some millions of years ago has not yet been definitely established.

(*b*) $He \rightarrow C^{12}$. The exhaustion of H in the core results in an eventual contraction and heating. Before the temperatures or densities become high enough to produce neutrons or to start endothermic reactions, the probability of the reaction ${}^2He^4 + {}^2He^4 \rightarrow {}^4Be^8$; ${}^4Be^8 + {}^2He^4 \rightarrow {}^6C^{12}$ becomes appreciable (Salpeter). The production of C^{12} during contraction of a hydrogen-poor core starts at 2×10^8 ° K. Thus a possible explanation exists for the carbon stars, subject to the further problem of mixing. If the envelope of the star is hydrogen-poor, then mixing will alter the composition so that the spectrum will be notable for an abnormally high ratio C^{12}/C^{13} with weak CH and hydrogen lines. Such stars have in fact been found to exist (Sanford, Bidelman). If the envelope is not hydrogen-poor and has a shell-source in which the C–N cycle is going on, then C^{12}-rich material streaming through it may assume the C^{12}/C^{13} ratio of 4/1 when mixing occurs. This would explain most of carbon stars observed by McKellar. In addition to the C^{13} produced, another consequence will be the production of N^{14} equal in amount to C^{12}, resulting in an N/C ratio probably different from the primeval value.

A group of stars exists in which the observed abundance anomalies affect the heavier elements. Their common spectroscopic features (which occur at a variety of temperatures) indicate the possibility that elements of the fifth and sixth periods are somewhat more abundant relative to those of the fourth. Indications of 'heavy-element' stars include the following. The S-type stars have recently been shown (Merrill, Buscombe) to have a high abundance of both ZrO and Zr. Thus the strength of ZrO is probably a real abundance effect, not only due to the dissociation equilibria favouring the bands of ZrO. In addition Y and Nb are enhanced relative to the iron-group metals. The extraordinary discovery has been made (Merrill) that lines of the radioactively unstable element Tc (maximum known lifetime 2×10^5 years) appear in S stars. (Tc is the heavy analog of Mn.) At earlier spectral types a group of G and K stars exists in which the heavy elements are strengthened. For example, in *ζ* Cap (Bidelman, Greenstein) Sr, Ba, La and especially many of the rare earths appear anomalously strong compared to the iron-group elements. Quantitative analysis of these stars is in progress; the nuclear processes which may have caused these anomalies have not yet been identified. The most obvious one, neutron capture, requires a very high neutron flux.

Finally, we should explore the composition differences dependent on stellar origin. The spectroscopic differences between stars of population type I and II in the solar neighbourhood are small, but are now well established. Quantitative analysis of F dwarfs (Schwarzschild) indicates a higher ratio of hydrogen to the metals in the high-velocity group. Slight weakening of all metallic lines in the high-velocity F stars has been detected (Roman). It should be remarked that the types of differences between low- and high-velocity stars are more complex than has been generally assumed. For example, giant G stars of high velocity with either *strong* or *weak* CN exist (Roman, Keenan, Greenstein). The red giant stars in some globular clusters have more anomalous spectra, notable for a large difference between spectral features and photoelectric colour (Baum).

But, in general, weakening of CN is a feature of many (but not all) high-velocity G and K giants. This CN weakening (and CH strengthening) has been shown to arise from higher hydrogen abundance (Schwarzschild, Spitzer, Wildt) relative to both C, N, O and to the metals. Analysis of the high-velocity stars with strong CN has not yet been carried out.

The same type of composition difference has been found from the analysis of the subdwarf spectra (Chamberlain, Aller). These stars have extremely high velocity; they must be of population type II. Their spectra are marked by weak metallic lines: analysis shows that the abundance of Fe and Ca may be as low as one-tenth that in the Sun.

Thus the high-velocity stars, giants, dwarfs and subdwarfs, appear to differ basically from the low-velocity stars by having a relatively low abundance of the heavier elements. This difference may have originated as follows. At the early time when population II stars were formed, interstellar dust may have been lacking and stars were formed solely from the original gas. Accretion, since then, cannot have substantially affected the composition of the type II stars. Subsequently, dust may have condensed from the gas and this dust (rich in the heavier elements) may have played an important role at the later epochs (continuing into the present) in which the population I stars were formed.

Discussion du rapport de M. SCHWARZSCHILD *et* J. L. GREENSTEIN

A. G. Masevich demande si les étoiles de population II proviennent des étoiles de population I et s'il y a des étoiles jeunes dans la population II.

Schwarzschild pense que dans les deux populations, les étoiles se forment sur la séquence principale. Les étoiles de la population II s'en écartent car elles ont le temps, elles sont vieilles.

Hoyle fait remarquer qu'il est évident que les sous-naines sont pauvres en éléments lourds.

Gratton fait les remarques suivantes sur les différences de composition chimique entre population I et II.

What is the factor or the factors which are decisive for determining the type of stellar population of a star or a group of stars? Observationally the only possibility to investigate this point resides in a spectroscopic comparison between stars belonging to both populations; in practice this can be done with sufficient dispersion only for stars of high and low velocity of the same spectral class.

Already Oort in his paper of 1926(1) discussed the possibility of spectral differences between high- and low-velocity stars, but only several years later was it discovered by Morgan, Keenan and Kellman(2) that the CN bands are abnormally weak in high-velocity giants of the spectral types G5–K2. Afterwards Popper(3) found that the same was true for the K giants belonging to the globular clusters M3 and M13. It may be remarked that although M3 is very rich and M13 very poor in variables, their giant sequences do not show any pronounced difference. It appears, therefore, that the difference in strength of CN bands might well be typical between K stars of population I and population II.

Unfortunately, the intensity of CN bands depends strongly on physical factors (absolute magnitude effect!) and is not readily interpreted.

Studying the spectra of R stars, Keenan(4) found, on the other side, that the CH band at $\lambda = 4300$ was enormously strengthened in R stars of high velocity, as compared with low-velocity stars of the same class, while the CN bands were again fainter in the high-velocity stars. Keenan, Morgan and Münch(5) found also a tendency of the CH band to be stronger in high-velocity stars of the types G–K and this was confirmed by Miczaika(6), who was unable to find any noticeable difference in the atomic lines, although the aforementioned authors suspected the Balmer lines to be stronger in high-velocity stars.

All these investigations employed rather small dispersions which do not permit a detailed analysis. M. and B. Schwarzschild(7), working with higher dispersion, made a comparative study of F dwarfs of high and low velocity.

Again it was found 'with fair certainty' that CH is stronger in high-velocity stars, which indicates that the abundance of C relative to the metals is probably 2·5 times larger in the high-velocity than in the low-velocity F dwarfs. The differences in strength of atomic lines were found exceedingly small, but if we accept it as real it would mean that the abundance ratio H to Fe is approximately twice as great in high-velocity stars compared with that in low velocity ones.

The large abundance of H was confirmed by an investigation of Chamberlain and Aller(8) on the spectra of A type subdwarfs. They found that in the normal A4 dwarf 95 Leonis, Ca and Fe are practically equally abundant as in the Sun, whereas in the two subdwarfs HD 19445 and HD 140283 (both high-velocity stars) they are of much lower abundance.

The Ca I and Ca II lines were investigated by means of their profiles and those of Fe I and Fe II by means of the conventional method of the curve of growth. Thus subdwarfs have very high H content relative to metals.

We may quote also two investigations by Miss N. Roman(9); she found that among giants and dwarfs of spectral types F5–G5 some stars have lines systematically weaker than others. If the stars are divided in two groups, those with weak lines were found to possess on the mean larger velocities and larger deviations from the mean velocity than those with strong lines; stars with high velocity are found only among those with weak lines. Things are more complicated for K giants. According to Miss Roman we may distinguish several groups, but what is especially interesting for us is that all groups with higher velocity tend to show an enhancement of the G band; the group of stars with CN abnormally weak for their absolute magnitudes is very definitely a high-velocity group.

In 1948 I began an investigation of the spectra of K giants mainly with the aim of comparing with the highest dispersion available the spectra of high-velocity stars like α Bootis, γ Leonis A, η Cephei, η Serpentis with 'normal' stars like η Draconis, α Serpentis, β Ophiuchi, α Ursae Majoris and others. Only the regions $\lambda\lambda$4000–4300, with a total of little more than 200 lines for each star has been measured photometrically as yet as there are still some difficulties connected with the spectrophotometric technique.

We find a tendency for lighter metals (Sc, Ti, V) to be stronger in the high-velocity stars as compared with the group of Cr, Mn, Fe, while Co is decidedly stronger relative to Fe. Ca, however is definitely fainter especially in α Boo. Y and Zr do not show a definite behaviour. Among the rare earths, Ce is apparently fainter, while Nd, Sm and, probably, Eu are stronger in high-velocity stars. All these conclusions need to be confirmed by a more complete discussion.

Among the molecules the most remarkable fact is perhaps the behaviour of CH which does not show the expected strengthening in high-velocity stars. CN is very definitely fainter. Indeed, the weakening of CN is, perhaps, spectroscopically the only conspicuous feature in high-velocity stars.

The few subgiants compared form a group of stars rather scattered in absolute magnitude, it is therefore difficult to obtain definite results by a crude comparison. It may be said, however, that the preceding conclusions are not contradicted; apparently the only outstanding anomaly is the extreme weakness of CN in the low-velocity star β Aql. This, however, might be due to the faint absolute magnitude of this star (the faintest in my programme), which is, in fact, almost intermediate between the subgiants and the main sequence. Because of this difficulty the results for the subgiants are not given. The definitive analysis both for giants and subgiants will be made when all the plates have been completely measured.

The significance of these results is not clear. The most conflicting point is the faintness of the CH band in high-velocity stars. Schwarzschild, Spitzer and Wildt (10) have shown that if H and the elements of the O group (represented by C) are more abundant than metals in high-velocity stars, we should find CH enhanced and CN and Fe weakened in these stars. This is in agreement with previous findings, but my results disagree as far as CH is concerned. If, however, we would adopt a somewhat smaller increase of the ratio of H to metals (A) than that assumed by the aforementioned authors, we probably would get a theoretical variation of molecular bands not in contradiction with my observations. I should like to point out that the weakening of SiH in high-velocity stars might be interpreted as due to an increase of the O to metals ratio (B), due to the formation of SiO.

The present discussion for K giants is admittedly very crude and the final analysis must be made before arriving at conclusions, although I do not see how the preceding results might be seriously changed.

Leaving aside smaller differences, it seems on the whole that we should admit in high-velocity stars a somewhat larger H to metals (A) ratio and also a larger O to metals (B) ratio. This is in agreement with the views expressed by Schwarzschild, Spitzer and Wildt. It must be observed, however, that the present spectroscopic evidence, although not unfavourable, is rather weak. The general difficulties connected with the interpretation of the kinematical properties of K giants cannot be neglected and suggest great caution. Above all we must bear in mind the possibility of transition cases, which are strongly suggested by the distribution of velocities.

Also the spectroscopic observations point toward an intermediate value of (A) for K giants as compared with normal dwarfs and giants on one side and with subdwarfs and high-velocity dwarfs on the other side.

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8. *Exposé de* B. STRÖMGREN

Strömgren gave a brief analysis of three points dealt with in his article on 'Evolution of Stars' (*A.J* **57**, 65, 1952):

1. For main-sequence stars the extent of the convective regions changes with the mass. The more massive stars (A stars brighter than 2^m–3^m) have a convective core roughly corresponding to the Cowling model. The outer convection zone, first considered in connexion with problems of the solar interior by Biermann in 1938, is quite narrow. Passing from bright to faint main-sequence stars one finds that the extent of the convective core decreases, vanishing for faint stars. This is due to the fact that the energy-production mechanism changes from the carbon cycle to the proton-proton process,