35. COMMISSION DE LA CONSTITUTION DES ÉTOILES

PRÉSIDENT: M. CHANDRASEKHAR, *Yerkes Observatory, Williams Bay, Wisconsin, U.S.A.*

MEMBRES: MM. Atkinson, Bethe, Biermann, Mme C. M. Bondi, MM. H. Bondi, Cowling, Dingens, Gamow, Gratton, Hoyle, Kaplan, Kozyrev, Kothari, Lebedinsky, Ledoux, Lemaître, Lyttleton, McCrea, McVittie, Mme Masevich, MM. Milne†, Randers, Reiz, Rosseland, Russell, Schatzman, Schwarzschild, Severny. Strömgren, Thomas, Tiercy. Tuominen, von Weizsäcker, Von Zeipel, Wasiutynski.

In their reports for this Commission, the two past-Presidents (Sir Arthur Eddington and Prof. Henry Norris Russell) have presented their estimate of the progress in the general field of the internal constitution of the stars. They were, of course, eminently qualified to do so. However, it occurred to the present writer that it may be of interest to find out from the various members of the Commission what their individual assessments of the problems are and their own trends of thought and work. While all of the members did not respond to a circular letter sent to them, enough replies were received which together seem to summarize the present state of the subject. Therefore, departing from the tradition established by the past-Presidents of this Commission, the present report will consist of the statements sent to the writer by those members of the Commission who responded to his inquiry. But before presenting their various statements, it may be of interest to record here the following extract from a letter dated 20 August 1948 which the present writer received from Prof. E. A. Milne after the last meeting of the International Astronomical Union.

You have been appointed President of the Commission on Constitution of the Stars. In Russell's absence, I presided over the session of this Commission at Zürich. There was a feeling expressed in connection with the Commission's resolution welcoming a new edition of the *British Association Emden Tables* (8), that it would be well to extend these tables to include, for certain polytropic indices, numerical solutions other than those finite at the centre. Several members spoke in favour of this but it was agreed not to make a formal resolution but to leave it for the next General Assembly. May I therefore raise it with you formally? I think that for a limited number of values of n, solutions should be published both for $\omega_n < \omega^\circ_n$ and $\omega_n > \omega^\circ_n$ with associated values of what I used to call u and v, solutions other than those tending to a constant at the centre, on the ground that such would be useful in dealing with stars stratified in finite spherical layers.

E. A. MILNE (*Oxford, England*)

Professor Milne's interest in the general solution of the equations of stellar structure is well known; and his use of the homology invariant variables $u(=4\pi\rho r^3/M(r))$ and $v(=2GM(r)\rho/5Pr)$ still represents, in many ways, the best choice In this, as in other fields of astrophysics, Prof. Milne was a great pioneer and his death removes the last of the great triumvirate, Eddington, Jeans, Milne, who dominated theoretical astronomy during the quarter-century 1910–35.

REPORTS FROM MEMBERS OF THE COMMISSION

Writing on behalf of herself, H. Bondi, F. Hoyle, and R. A. Lyttleton, Mrs C. M. Bondi transmitted references to Papers (1–7), (27), (35–43) and (54) listed at the end of the report. (See also supplement to this report.)

The only paper (12) I have published during the period in question is the one on oscillations of a rotating star. I have a very small piece of work on hand at present on convection in a rotating star (11). Personally, I believe that the subject of turbulence in a rotating star needs tidying up and this is a subject which might be brought to the notice of the International Astronomical Union.

T. G. COWLING (*Leeds, England*)

It is a well-established fact that energy production in stars is due to the thermonuclear transformation of hydrogen into helium. Since hydrogen forms about one-half of normal stellar material, the rate of its consumption, that is, the luminosity of the star, determines the stellar life-span; in the case of our Sun it can be calculated to be about fifty thousand million years, which is very long as compared with the estimated age of the stellar universe. Since, however, stellar luminosity (hydrogen consumption) increases very rapidly with stellar mass (hydrogen content), the life-spans of brighter stars are considerably shorter. Thus stars of about zero absolute magnitude would run through their hydrogen evolution in a few thousand million years, that is, in a period of time which is generally accepted as representing the age of our universe. Indeed, we notice that the stars of zero absolute magnitude seem to represent a demarcation line in the stellar population of our galaxy. Thus the main sequence of the Russell-Hertzsprung diagram shows a noticeable discontinuity at that particular point. The brighter stars are very scarce in space and are in a state of rapid axial rotation; the fainter stars are very abundant and scarcely rotate at all. Also, within stellar population II, as defined by Baade (the regions of the galaxy where no interstellar material is present), the upper part of the main sequence is completely absent.

All this suggests that zero absolute magnitude divides the main sequence into the older (lower) part containing the original stock of stars formed almost simultaneously a few thousand million years ago, and the younger (upper) part consisting of stars formed by condensation processes at various more recent epochs. We may also notice that zero absolute magnitude serves as an apex from which the main sequence of stars branches out into 'swollen-up' stellar types such as pulsating variables and red giants in general, and 'shrunken' stellar types which include Wolf-Rayet stars, nuclei of planetary nebulae, white dwarfs, and various types of exploding stars (U-Geminorum, recurrent novae, ordinary novae and supernovae). It is difficult to escape the impression that stars deviating from the main sequence are those which have run out of their original hydrogen supply, a situation which forces them to go through 'unusual' final stages of their evolutionary life. One would expect, in fact, that all these stars would have comparable masses (at least at the stage when they leave the main sequence) of the order of magnitude of three sun masses and about the same total life-span of a few thousand million years. This conclusion finds support in the Kukarkin-Parenago relation, according to which the intensity of periodic stellar explosions (U-Geminorum stars, and recurrent novae) is directly proportional to the period between explosions. This relation, indicating a constant total rate of energy production, would be difficult to understand for stars of different masses and, consequently, different central temperatures.

If we look at this problem from the point of view of possible stellar models, we find that an ageing star would be expected to develop a so-called 'shell-source' of nuclear energy (13), (20, 21), (22). In fact, when all the material in Cowling's convective zone supplying fresh fuel for nuclear reactions in the centre is completely dehydrogenized, the reaction would transfer itself into a spherical layer between the isothermal helium core, and the radiative hydrogen-rich envelope. The properties of such shell models have been studied by many authors, with rather interesting results. It has been found that an attempt to fit a small isothermal core into a radiative envelope (with the temperature and pressure continuous at the interface) results generally in several possible solutions. One of these gives a star of extremely large radius which can be considered as a tentative model of a red giant (65–7). The other two solutions lie rather close to one another, representing stars of more or less normal size (33). However, when the fraction of the stellar mass in the core increases (due to the progressive nuclear reaction) these two solutions disappear (34), (78), (31, 32), leaving the evolving star in an odd position of 'not knowing what to do'

The situation is that when we plot the pressure at the interface of the envelope against the radius of the envelope we have a curve which has a maximum and a minimum, while the corresponding curve of pressure at the interface against the radius of the core is monotonic decreasing. Consequently we may have three intersections between the two curves when the core is small and none when the core is large. The disappearance of two intersections for larger cores means physically that it is no longer possible to fulfil the continuity conditions both for temperature and pressure. If we 'force' a solution for some interface-radius r_i, we find an inversion of pressure and the star will start to collapse. We can, of course, stabilize the model by raising the temperature (and hence the pressure) at all points of the core; but this will produce a non-stationary thermal state, and lead to gradual heating of the inner layers of the hydrogen-containing envelope. The situation is rather analogous to that in an ordinary electric bell, where the clapper can neither stay at the electromagnet nor at the electric contact. It is difficult to predict the behaviour of the model without rather elaborate hydrodynamical calculations (23); but it is apparent that at this point of evolution the static model must go over into some kind of periodic motion. When the stability conditions are just exceeded, we would expect short-period motion with small amplitudes. As the core grows, both period and amplitude would be expected to become larger and larger. Thus, we have here a picture which may be useful for the explanation of the Kukarkin-Parenago relation, provided we consider different U-Geminorum stars as successive evolutionary stages of a single stellar mass. It may, indeed, easily happen that the 'oscillations' described above will result in periodic convectional instabilities. In this case a rapid mixing of cool hydrogen from the envelope with hot helium from the core will result in periodic nuclear explosions of the star. There is also the possibility that similar instabilities may develop in 'swollen-up' solutions of the shell-model. If the resulting central explosions are comparatively weak, they will not show through the thick body of the star and may act as a 'buzzer' mechanism for maintaining regular stellar pulsations.

It is too early to say whether or not the above views will lead to a correct explanation of the dynamical states of ageing stars. The study of the hydrodynamical equations involved in the problem is extremely difficult, and can be done only by means of modern electronic computers. Work in this direction is now being done by the author and his colleagues, A. Carson, G. Keller, C. Longmire, N. Metropolis, L. Peck and R. Richtmeyer, with the hope of having solutions run on a new electronic computer ('Maniac') under construction at the Los Alamos Scientific Laboratory.

G. Gamow (*Washington, D.C., U.S.A.*)

The publication of the La Plata Observatory (28) contains an investigation of Cowling's generalized model, together with some numerical tables which might be of interest to workers in this field (investigations of the point source model with negligible radiation pressure and Kramers' opacity law). The main result of this work is that during the phase of the exhaustion of the hydrogen contained in the core of a star through Bethe's cycle, its radius, luminosity and surface temperature remain practically constant.

Another investigation (29) refers to the chemical composition of binaries; the aim of this is to determine hydrogen and helium abundances using only Eddington's mass-radius-luminosity function (actually Cowling's model was used), without reference to the law of energy generation in order to avoid errors due to the uncertainty of the central temperature which is very sensitive to the model adopted. The two systems investigated (Alpha Centauri and Eta Cassiopeiae) gave, however, two equations which are incompatible. Of course, this might be due to errors of the observational data; but as these ought to be supposed rather too large to make the system compatible, there are still open the two possibilities, either that the model is insufficient for computations of the chemical composition of the stars or that there are systematic differences of composition between the two components of a binary.

L. Gratton (*La Plata, Argentina*)

Mr K. Osawa (61) has shown that the differential equation of the problem of stellar envelopes for the purposes of evaluating the central condensation of stars may be solved easily by a graphical method, in which the change of mass is taken into account. Several curves of the constant degrees of central condensation are drawn on the mass-luminosity diagram.

He has also constructed a star-model (62) built with a convective core and a radiative envelope with a constant opacity. And he has shown that the Trumpler stars may not be interpreted on the basis of the present model unless it is assumed that the mean molecular weight of the core is smaller than that of the envelope.

Y Hagihara (*Tokyo, Japan*)

A good deal of time has been devoted to the study of non-radial pulsations of gaseous stars with or without rotation.

In the case of a star without rotation, the general fourth order differential equation has been re-established using as independent variable the quantity $(U'-P'/\rho)$ where U' and P' are the Eulerian perturbations of the gravitational potential and pressure. This equation is somewhat simpler than the equation derived by Pekeris (64) but it seems wellnigh intractable unless perhaps with the help of the new electronic computing machines.

On the other hand, it is felt that the approximation used by Cowling (10) and Kopal (46) (U' negligible) is likely to lead to fairly large errors on the periods for the first few modes of oscillations represented by spherical harmonics. Furthermore, the method of perturbations used by these authors to improve the values of the periods in a second approximation does not seem justified. No successful approximation has been found until now, but different possibilities are still under study.

It is believed that it would be important to determine precise values for the periods, at least for the fundamental mode of the spherical harmonic of degree two as it is likely to play an important role in some pulsating stars. For instance, one knows (12), (51) that if the star is rotating, five frequencies differing from each other only by simple multiples of the angular velocity will correspond to that harmonic (rank: $|m| \leqslant 2$) of which probably the components of rank $m=2$ would be most important. The frequencies of these two modes being very close to each other, beats would result which could perhaps account for the phenomena observed in variables of the type of RR Lyrae. In fact, it is easy to show that the necessary angular velocity is small, of the order of $\omega \simeq 10^{-6}$ (period of rotation 81 days) for RR Lyrae. Unfortunately, if we have some approximate expressions for the correction due to the rotation we do not know the period of the harmonic of degree two for a star without rotation and thus we cannot push the comparison with observations very far (52).

A further reason for this work was to try to disentangle the question of stability towards general perturbations and the general relation between dynamical stability and convective stability (10), (51). In all its generality this problem is very complicated and recently it was decided to tackle first the case of the external layers of the star where reasonable approximations reduce the equation to a simpler form. This investigation is in progress but no general results have been obtained yet.

As far as the effects of rotation are concerned, it is well known that the main difficulty in the general case is the elimination of U' This was possible in the case of the homogeneous compressible model (51), the resulting equation being of the second order. It has been shown that the elimination can also be performed without difficulty in the case of a rotating configuration in adiabatic equilibrium, but, of course, the equation is then of the fourth order and progress in this case is bound to progress in the case of the fourth order equation for non-rotating stars in adiabatic equilibrium (this is appreciably simpler than in the general case). However, in the case of rotating atmospheres, the equation can be safely reduced to a second order differential equation and this case is under study.

An investigation of the dynamical and vibrational stability of white dwarfs was made in collaboration with Mme Sauvenier-Goffin (70, 71) and led to the following conclusions. The dynamical stability of a white dwarf does not decrease as the degeneracy tends to become relativistic in the whole configuration, as a superficial analogy based on the value of γ would suggest, but, on the contrary, it increases (70, 71), (53). On the other hand, it was shown that if one takes into account the delays in phase between oscillations and the generation of energy in such a star, it would become vibrationally unstable for all nuclear reactions known. This implies that the energy must be liberated by some other process such as gravitational contraction and that the abundance of hydrogen must be extremely small except perhaps in the utmost external layers.

The recent paper by Milne (60) on the phase relationship between light and velocity curves in cepheids was also discussed and it is believed that his explanation must be rejected because, on the one hand, the variation of luminosity δL is such a small quantity as compared to the gravitational potential energy of the star and its internal energy or even to the kinetic energy of pulsation and the ionization energy of the external layers, while on the other hand

δL is of the same order as L and very large as compared to the variation of the generation of energy in the star.

Mlle D. Jehoulet, who is working on variable stars, has recently made a compilation of the data known in the case of about 100 cepheids concerning the asymmetry of their light-curves and the value of the ratio of their surface amplitude δR to the radius R. These data reveal a complete lack of correlation between $(\delta R/R)$ and the asymmetry, and thus the recent attempts to explain the asymmetry as due to the finite character of $(\delta R/R)$ must be viewed with caution.

Other problems which are under study by myself or students are the pulsations of stars with large magnetic fields (79), the constitution of red giants (models with varying molecular weight) and the internal constitution of planets.

P. LEDOUX (*Liége, Belgium*)

Miss Joyce G. Gardiner (24) working under my direction has approached the problem of red giant stars in a way different from that of the other workers who have recently obtained important results in this subject. She constructs a model as follows. She takes a set of typical values for the mass, radius and luminosity of a red giant. Assuming the outer part of the star to be pure hydrogen she integrates inwards from the boundary, the outermost layer being treated by Strömgren's methods for model stellar atmospheres. She uses the absorption coefficient for hydrogen as given by Unsöld and Strömgren but with some extension of their tables and with allowance for electron opacity where required. If she attempts to carry this integration to the centre she is left with excess mass, but if she allows for a change of chemical composition at a suitably selected level, she obtains a self-consistent model. Provisional figures for one example, a star of mass 5×10^{33} g., radius $2{\cdot}8 \times 10^{12}$ cm., and effective temperature 3580 deg., are: a change of composition from ('envelope') $X = 1{\cdot}0$, $Y = 0$ to (inner zone) $X = 0{\cdot}37$, $Y = 0{\cdot}63$ at radius 5×10^{10} cm.; mass of hydrogen 'envelope' $2{\cdot}3 \times 10^{33}$ g.; temperature at interface $2{\cdot}6 \times 10^{6}$ deg., convective core in inner zone, radius $2{\cdot}8 \times 10^{10}$ cm., mass 10^{33} g., temperature at interface $1{\cdot}2 \times 10^{7}$ deg., central temperature $1{\cdot}9 \times 10^{7}$ deg. Thus there is qualitative agreement with current ideas on the constitution of red giants. But the work raises further interesting questions regarding convective layers in the 'envelope' which have not yet been investigated. It is intended to study also cases of other chemical composition in the 'envelope'.

Miss Gardiner (25) working in consultation with Sadler and myself has attempted to provide a definitive integration of the Cowling model.

W. H. MCCREA (*London, England*)

Theoretical work has been mostly confined to problems of variable stars, and in the period under consideration the monograph *Pulsation Theory of Variable Stars* was published (68). A paper on a particular aspect of the pulsation problem: 'The Luminosity-Velocity Relation of Pulsating Stars', will appear shortly (69). This paper discusses the problem raised by Milne's recent paper (60) on the same subject.

Several problems are at present in a state of evolution at this Institute. First in line comes the task of deriving the complete solution of the problem first discussed by Schwarzschild (79) of a homogeneous and incompressible star of infinite electrical conductivity, oscillating under the influence of a constant and homogeneous magnetic field. One of my assistants, Miss Guro Gjellestad, has been detailed to handle this problem in close co-operation with me and considerable progress has been made (26). There seems to be reason to hope that the full solution may be obtained soon, showing the combined effect of magnetism and gravity (the latter was neglected by Schwarzschild).

We are, furthermore, greatly interested in the problem of the segregation of heavier elements towards the centre in pulsating stars and its possible effect on the pulsations. For this purpose solutions of the pulsation equation, corresponding to a spatially variable ratio of specific heats, are run on the differential analyzer by another of my assistants, Mr Eberhart Jensen. Two graduate students are also interested in some other phases of the 'γ-problem', but these investigations are not as far advanced as in the case of the magnetic oscillations.

S. ROSSELAND (*Oslo, Norway*)

1. Work has been in progress last year about the theory of the evolution of stars. I have been interested in the origin of white dwarfs. My first paper about that question (72) intended to prove that white dwarfs and main sequence stars have a different origin. It might be added that the time scale for the evolution of a star like the sun is too long for explaining the enormous number of white dwarfs we actually see. I still hope to find an explanation of the origin of white dwarfs, but that problem is very intricate and is related to the most speculative of the cosmogonical problems.

Struve (88) attracted my attention to different problems of the evolution of stars, especially to the treatment of Fesenkov and Masevich (55–9). I have tried to find the evolutionary path of rotating stars (75). But the hypothesis of Struve and Fesenkov that rotation might produce a continuous and rapid loss of matter seems to have to be rejected. That hypothesis would be justified only if a new process could be found by which stars can lose a large part of their mass.

2. I have begun the study of propagation of shock waves in stars and I have found a remarkable relation between the velocity, the mass and the energy in novae (76, 77) which seemed to justify the hypothesis that nuclear reactions were of importance in ordinary novae. Nevertheless, extensive calculations by Dumézil-Curien and myself (14, 15) lead almost certainly to the conclusion that nuclear reactions have nothing to do with ordinary novae. No shock waves, whatever their strength, could be generated by nuclear reactions. Concerning supernovae, no conclusion can yet be drawn.

3. I have extensively studied a model of white dwarfs, with hydrogen shell surrounding a core of heavy elements. A table of models (74) has just been published. Questions related to the problems of energy generation in white dwarfs are solved, but the question of vibrational stability is still open. The models of white dwarfs which Ledoux and Sauvenier-Goffin (53) have studied for testing the vibrational stability are not exactly those I proposed (73). The high temperature of my last models favours the vibrational stability. Work is in progress on these questions.

4. Epstein's (19) conclusions concerning the possible influence of the convective zone are quite in agreement with my own ideas on these questions. Actually work is in progress at the Institut d'Astrophysique, concerning the fitting of a convective zone to a radiative zone in stellar atmospheres. Considerable progress has been achieved by Cayrel in a paper appearing soon (9). Charlotte Pecker and I are investigating precisely which stars have an extensive hydrogen convective zone and which stars have not. The conclusions we hope to obtain will naturally be used for the pulsation theory of giant stars.

E. SCHATZMAN (*Paris, France*)

Regarding the internal constitution of the red giants, attention has been concentrated mainly on models with chemical inhomogeneities. Included in recent studies were both models with unexhausted (convective) cores and models with exhausted (isothermal) cores.

It appears now fairly certain that very large radii can be obtained under physically reasonable circumstances for models with a mean molecular weight near that of helium in the core and near that of hydrogen in the envelope. The largest radii occur generally if the change in molecular weight is located so as to divide the star into two parts nearly equal in mass. This seems to be true whether the change over occurs discontinuously or is spread continuously over an appreciable depth.

For the inhomogeneous models with very large radii the theoretical developments indicate a considerable deviation from the usual mass-luminosity relation (in the sense of relatively small mass for a given luminosity). No such deviation is indicated by the observational data on the masses of red giants; these data are, however, extremely weak and in urgent need of improvement.

As possible causes for chemical inhomogeneities in stellar interiors the following have been considered: (*a*) reduction of hydrogen in the core by nuclear processes, and (*b*) increase of hydrogen in the envelope by accretion. Under either assumption the inhomogeneity should tend to increase during the lifetime of a star. The question of whether the development of an inhomogeneity might be prevented by mixing processes under certain conditions seems at present unanswered.

I attach a list of papers, (79), (80), (81), (82), (17–19), which we have published on subjects relating to the internal constitution of the stars.

MARTIN SCHWARZSCHILD (*Princeton, N.J., U.S.A.*)

1. Mme A. G. Masevich (55, 56) examina les lois d'évolution des étoiles de la Série Principale dans l'hypothèse de la perte de masse par radiation corpusculaire. La résolution commune des équations d'équilibre des étoiles avec la relation masse-luminosité permet d'obtenir théoriquement la Série Principale des étoiles sur le diagramme luminosité-spectre (c.-à-d. la deuxième relation empirique masse-rayon). En même temps (57, 58) elle explique la variation de la composition chimique le long de cette série dans le cadre des opinions existantes sur les sources d'énergie stellaire et conduit à des termes raisonnables d'évolution des étoiles (notamment du Soleil) et à une loi de proportionalité entre la luminosité et la diminution de la masse. La dispersion observée des luminosités absolues pour les étoiles de la Série Principale peut s'expliquer par l'évolution des étoiles à composition chimique initiale différente (à teneurs différentes d'éléments lourds). Il est possible d'expliquer d'une manière analogue les différences entre les contours de la Série Principale dans les amas galactiques (59).

2. P P. Parenago et Masevich (63) considérèrent la relation entre les paramètres fondamentaux de 240 étoiles à masses connues. Ils montrèrent qu'il n'éxistait pas de relation unique masse-luminosité pour toutes les étoiles. En particulier, la Série Principale se divise en deux groupes de O8 jusqu'à G4 et de G7 jusqu'à M (pour le premier la relation masse-luminosité est $L \sim M^{3,9}$ et pour le second $L \sim M^{2,3}$). Pour les sous-naines et les sous-géantes il n'existe pas de relation exclusive entre la masse et la luminosité et le théorème de Vogt-Russell ne s'applique pas à ces étoiles. Ces auteurs démontrèrent que le modèle à coefficient d'absorption constant était inapplicable aux étoiles réelles.

3. N. A. Kozyrev (47) à base d'analyse des relations observées 'masse-luminosité', 'période-densité moyenne' et des équations fondamentales de la structure stellaire obtint les résultats suivants:

(i) Dans toutes les étoiles (les super-géantes comprises) le rôle de la pression de radiation n'est pas essentiel et peut être négligé devant la pression des gaz;

(ii) L'intérieur des étoiles est presqu'entièrement constitué par l'hydrogène (poids moléculaire moyen voisin de 1/2);

(iii) L'absorption de la lumière est conditionnée par la diffusion sur les électrons libres (effet Thompson);

(iv) Les étoiles ont des structures voisines des polytropes de la classe $e/2$. A base de ces résultats l'auteur estime à près de 6000000° la température du centre du soleil.

4. N. A. Kozyrev (48) construisit également le diagramme donnant la capacité des sources d'énergie $\epsilon = L/M$ en fonction des conditions physiques au centre, pour 150 étoiles dont les grandeurs, L, M, R sont connues.

La répartition des étoiles réelles dans les limites d'une certaine région permit de construire un système 'isoerg' et montra que ϵ était une fonction univoque des conditions physiques Elle permit également à l'auteur de tirer cette conclusion que l'émission d'énergie dans les étoiles ne s'effectuait pas par des réactions nucléaires. L'émission de l'énergie dans les étoiles serait, d'après l'auteur, un phénomène thermique particulier n'obéissant pas aux lois courantes de la thermodynamique et de la mécanique.

5. Une vaste étude de A. B. Severny (83) sur la stabilité et les vibrations des sphères gazeuses et des étoiles parut dans les *Publications de l'Observatoire Astrophysique de Crimée*. L'auteur démontra rigoureusement l'instabilité des sphères gazeuses pour les rapports des chaleurs spécifiques $\gamma < 4/3$. La stabilité relative aux vibrations radiales subsiste pour $\gamma > 4/3$. Par la méthode de W. Ritz furent calculées les périodes des pulsations des sphères d'Emden. Ainsi fut obtenue une expression plus exacte de la relation 'période-densité' pour une étoile standard, qui s'accorde mieux avec les observations que les relations antérieures. Fut considérée en détail l'influence de la composition chimique, des modes de formation d'énergie et de la viscosité turbulente sur la stabilité des étoiles. Furent élaborées de nouvelles

méthodes analytiques pour l'étude de la stabilité pour le cas des vibrations non radiales ou de la rotation des sphères gazeuses. L'auteur trouva que l'accroissement de la vitesse de rotation s'accompagnait d'une diminution de la réserve de stabilité.

6. Dans ses compléments à l'édition russe de l'œuvre de Chandrasekhar (84), A. B. Severny publia les résultats de ses recherches sur la concentration de l'hydrogène et de l'hélium à l'intérieur des étoiles. Ces recherches sont basées sur la solution du problème relatif à la structure d'une étoile présentant un accroissement considérable de la concentration des sources énergetiques vers son centre. Pour le cycle du carbone chez les étoiles de la Série Principale la concentration de l'hydrogène augmente et celle de l'hélium diminue (dans les limites de ~ 10% à ~ 80% pour ces deux éléments) à mesure de l'augmentation de la masse de l'étoile.

7. A. I. et V S. Sorokine (86) étudièrent la stabilité des sphères gazeuses et notamment de la sphère gazeuse isothermique pour les cas de dégénérescence à différents degrés. Ils trouvèrent pour la sphère isothermique l'existence de rayons critiques pour lesquels la stabilité est conservée.

8. V S. Sorokine et Masevich (85) considérèrent pour une étoile du type de Soleil l'évolution résultant de la combustion de l'hydrogène dans le noyau convectif. Ils montrèrent pour le rapport des poids moléculaires de l'enveloppe du noyau (~2) l'existence d'une limite rendant une solution possible. Deux voies restent donc admises pour l'évolution (sans dépasser les limites de la Série Principale): combustion complète de l'hydrogène avec conservation de la structure et un changement catastrophique de la structure.

9. A. I. Lebedinski et L. E. Gourevich (49, 50) étudièrent (par analogie avec la théorie des explosions thermo-chimiques) la théorie des explosions thermiques, conditionnées par des réactions nucléaires à l'intérieur des étoiles. En cas de variation évolutive de la structure stellaire on constate les changements de la vitesse d'émission de l'énergie et du transfert de la chaleur et celui de la possibilité de formation de l'onde détonante. L'apport à la surface d'énergie explosive dure, d'après les calculs des auteurs, plusieurs dizaines de minutes. C'est par de telles explosions dans leurs couches périphériques que s'expliquent les augmentations brusques d'éclat des Novae.

10. G. S. Ivanov-Kholodny (44) tint compte de la variation du 'facteur guillotine' le long de la Série Principale et démontra la possibilité de conservation du poids moléculaire moyen pour les étoiles de G8 à M.

11. S. A. Kaplan (45) étudia la structure et l'évolution des naines blanches dans l'hypothèse d'une source gravitique de leur énergie, ce qui l'amena pour les naines du type Ross 627 à une durée d'existence d'environ 10^{10} années.

A. B. Severny (*Moscow, U.S.S.R.*)

In 1938 Biermann showed that if the temperature gradient in the hydrogen convection zone in and below the photosphere of the Sun is equal, or nearly equal, to the adiabatic gradient, then the convective instability will extend far into the solar interior and thus considerably affect the entire structure of the Sun. The problem of the relative importance of turbulent energy transport in the solar hydrogen convection zone has not been definitely solved, and the question raised by Biermann's investigation is still open. However, the fact that the relative lithium abundance in the solar atmosphere, though small, is not entirely negligible (30) indicates that the hydrogen convection zone, which must be assumed to be well mixed, cannot extend to depths where the temperature is higher than three to four million degrees, as this would lead to practically complete disappearance of the atmospheric lithium through thermonuclear processes. Biermann in the investigation mentioned estimated that the convective zone would extend to a depth where the temperature is somewhat over ten million degrees. Thus the hypothesis of adiabatic gradient in hydrogen convection zone, and corresponding extension, might seem to be ruled out. However, a revision of Biermann's calculation based on the now generally accepted chemical composition of the solar atmosphere and on the assumption of adiabatic temperatures throughout the convectively unstable zone (this is in fact compatible with the upper limit derived from the lithium argument (87)) leads to an extent only to a depth where the temperature is equal to about 2×10^6 degrees. Although the question of the temperature gradient in the hydrogen convection zone is still unsolved, it may be safely concluded that the influence of the zone of the interior structure cannot be very great.

Recent calculations by Epstein (19) indicate that the central convection zone of the Sun is considerably smaller than has been found previously due to the rule of the proton-proton process energy production. There is considerable energy production outside the convective core. While the two convection zones considered are presumably well mixed, mixing in the intermediate extensive zone in radiative equilibrium is probably insignificant during a time-scale of 3×10^9 years. Eddington (16) gave an upper limit to the speed of mixing caused by the rotation of the sun, but as Schwarzschild has pointed out (unpublished), this is a very generous upper limit and rotational mixing appears to be negligible for the Sun. This conclusion has recently been confirmed through a detailed investigation by Sweet (89). From this investigation it follows, however, that certain rapidly rotating stars might be well mixed through the currents set up by rotation.

It follows from what has been said that for main-sequence stars of the solar type one might expect the gradual transmutation of hydrogen into helium to lead to structures that are characterized by appreciable variation of molecular weight through a region outside the convective core. The influence of such a region upon the structure is being investigated. For more massive main-sequence stars, where energy production is practically limited to the convective core, detailed analysis of the evolutionary changes, assuming no mixing in the non-convective region, would appear to be very desirable.

B. Strömgren (*Williams Bay, Wis., U.S.A.*)

Recommendations from Members of the Commission

In addition to the foregoing reports of scientific work, Dr E. Schatzman (Paris) and Prof. A. B. Severny (Moscow) have communicated the following recommendations for the Commission to consider at its next meeting.

1. I think it might be useful to have Marshak's tables on equations of state of matter in unusual conditions of density and pressure published.

2. Cosmological problems have been extensively studied, both in U.S.A. and U.S.S.R. Not all of that work is valuable. But Ambartsumian, Chandrasekhar, Fesenkov, Struve, ter Haar and others have published important contributions to cosmological science, setting cosmology on a non-speculative, scientific basis. I think it might be worth while to suggest the creation of a Commission of Cosmology.

3. I think the general assembly should express the desire of astronomers of free exchange of scientific information and free relations of astronomers throughout a peaceful world, that peace is necessary to astronomy, that secrecy and war would be its doom and death.

E. Schatzman (*Paris, France*)

Lès représentants soviétiques à la Commission attirent l'attention des autres membres sur l'opportunité de concentrer les efforts sur l'étude des problèmes suivants et de prendre des mesures en conséquence:

(*a*) Problème de l'évolution des modèles d'étoiles avec écoulement de matière (étoiles WR, étoiles péculiaires et étoiles C).

(*b*) Étude du rôle des tensions turbulentes pour l'établissement de l'équilibre des étoiles.

(*c*) Problème de l'équilibre des étoiles en rotation avec variation des vitesses angulaires à l'intérieur de l'étoile.

(*d*) Étude sur la possibilité de formation de noyaux de neutrons à l'intérieur des étoiles.

(*e*) Il y aurait lieu d'introduire une motion sur la publication des données de Trumpler (notamment les classes spectrales) pour les amas galactiques ouverts.

(*f*) La Commission No. 35 devrait procéder au tirage et à la distribution à tous ses membres de graphiques pour l'intégration des équations de la structure stellaire dues à Bondi.

A. B. Severny (*Moscow, U.S.S.R.*)

In concluding this report, the undersigned wishes to record his thanks to all those members of the Commission who responded to his circular letter. The generosity of their response has made it possible to present a report representative of the state of the subject at the present time.

S. CHANDRASEKHAR
President of the Commission

REFERENCES

The following references are to the papers which are quoted in the reports by the members of the Commission. It is not to be regarded as a complete (or even representative) bibliography in any sense.

(1) BONDI, C. M. *M.N.* **108**, 324, 1948.
(2) BONDI, C. M. *M.N* **109**, 571, 1949.
(3) BONDI, C. M. *M.N.* **110**, 275, 1950.
(4) BONDI, C. M. and BONDI, H. *M.N.* **109**, 62, 1949.
(5) BONDI, C. M. and BONDI, H. *M.N.* **110**, 287, 1950.
(6) BONDI, C. M. and BONDI, H. *M.N* **111**, 397, 1951.
(7) BONDI, H. *M.N.* **110**, 595, 1950.
(8) *British Association Mathematical Tables.* London, 1931.
(9) CAYREL, R. *Ann. Ap.* **14**, 1, 1951.
(10) COWLING, T. G. *M.N.* **101**, 367, 1941.
(11) COWLING, T. G. *Ap. J.* **114**, 272, 1951.
(12) COWLING, T. G. and NEWING, R. A. *Ap. J* **109**, 149, 1949.
(13) CRITCHFIELD, C. and GAMOW, G. *Ap. J* **89**, 244, 1939.
(14) DUMÉZIL-CURIEN, P. and SCHATZMAN, E. *Ann. Ap.* **13**, 80, 1950.
(15) DUMÉZIL-CURIEN, P. and SCHATZMAN, E. *Ann. Ap.* (in the Press).
(16) EDDINGTON, A. S. *M.N* **90**, 54, 1929.
(17) EPSTEIN, I. *Ap. J* **112**, 6, 1950.
(18) EPSTEIN, I. *Ap. J* **112**, 207, 1950.
(19) EPSTEIN, I. *Ap. J* **114**, 438, 1951.
(20) GAMOW, G. *Ap. J.* **87**, 206, 1938.
(21) GAMOW, G. *Physic. Rev.* **67**, 120, 1945.
(22) GAMOW, G. and KELLER, G. *Rev. Mod. Phys.* **17**, 125, 1945.
(23) GAMOW. G. and LONGMIRE, C. *Physic. Rev.* **79**, 743, 1950.
(24) GARDINER, J G. *M.N.* **111**, 94, 1951.
(25) GARDINER, J. G. *M.N.* **111**, 102, 1951.
(26) GJELLESTAD, G. *Magneto-hydrodynamic oscillations of a star*, Part 1, Report No. 1. The Institute of Theoretical Astrophysics, Blindern, Oslo, Norway, 1950.
(27) GOLD, T. *M.N.* **109**, 115, 1949.
(28) GRATTON, L. *Publicaciones del Observatorio Astronómico de la Universidad Nacional de La Plata*, **28**, 5, 1949.
(29) GRATTON, L. and CORVALAN, M. I. *Publicaciones del Observatorio Astronómico de la Universidad Nacional de La Plata*, Circular No. 8, p. 12, 1951.
(30) GREENSTEIN, J. *Ap. J* **113**, 531, 1951.
(31) HARRISON, M. H. *Ap. J* **103**, 193, 1946.
(32) HARRISON, M. H. *Ap. J* **105**, 322, 1947.
(33) HAYASHI, C. (private communication).
(34) HENRICH, L. R. and CHANDRASEKHAR, S. *Ap. J* **94**, 525, 1941.
(35) HOYLE, F. *M.N.* **106**, 255, 1946.
(36) HOYLE, F *M.N.* **106**, 343, 1946.
(37) HOYLE, F. *M.N* **106**, 384, 1946.
(38) HOYLE, F. *M.N* **107**, 231, 1947.
(39) HOYLE, F. *M.N.* **107**, 253, 1947.

(40) Hoyle, F. *M.N* **107**, 334, 1947.
(41) Hoyle, F. and Lyttleton, R. A. *M.N* **106**, 525, 1946.
(42) Hoyle, F and Lyttleton, R. A. *M.N* **107**, 246, 1947.
(43) Hoyle, F. and Lyttleton, R. A. *M.N* **109**, 614, 1949.
(44) Ivanov-Kholodny, G. S. *Sternb. Comm.* No. 5, 1940.
(45) Kaplan, S. A. *A.J. U.S.S.R.* **27**, no. 2, 1950.
(46) Kopal, Z. *Ap. J* **109**, 509, 1949.
(47) Kozyrev, N. A. *Crim. Publ.* **5**, 2, 1948.
(48) Kozyrev, N. A. *Crim. Publ.* **5**, 6, 1950.
(49) Lebedinski, A. I. and Gourevich, L. E. *C.R. Acad. Sci. U.R.S.S.* **55**, no. 9, 1947.
(50) Lebedinski, A. I. and Gourevich, L. E. *C.R. Acad. Sci. U.R.S.S.* **56**, no. 2, 1947.
(51) Ledoux, P. *Mém. Soc. R. Liége*, sér. 4, Vol. **9**, 1949.
(52) Ledoux, P *Ap. J* **114**, 373, 1951.
(53) Ledoux, P. and Sauvenier-Goffin, E. *Ap. J.* **111**, 611, 1950.
(54) Lyttleton, R. A. *M.N.* **106**, 228, 1946.
(55) Masevich, A. G. *A.J U.S.S.R.* **26**, no. 4, 1949.
(56) Masevich, A. G. *Bull. Acad. Sci. U.R.S.S.*, série physique, **13**, no. 6, 1949.
(57) Masevich, A. G. *Vestnik de l'Univ. de Moscou*, No. 8, 1950.
(58) Masevich, A. G. *A.J U.S.S.R.* **28**, no. 1, 1951.
(59) Masevich, A. G. *C.R. Acad. Sci. U.R.S.S.* **80**, no. 2, 1950.
(60) Milne, E. A. *M.N.* **109**, 517, 1949.
(61) Osawa, K. *Jap. Journ. Astr.* **1**, 1, 1949.
(62) Osawa, K. *Proc. Japan Acad.* **22**, no. 10, 1946.
(63) Parenago, P. P. and Masevich, A. G. *A.J U.S.S.R.* nos. 3 and 4, 1950.
(64) Pekeris, C. L. *Ap. J* **88**, 189, 1938.
(65) Reiz, A. *Ann. Ap.* **10**, 301, 1947.
(66) Reiz, A. *Kgl. Danske Vid. Sels.* **25**, 1948.
(67) Reiz, A. *Arkiv. f. Astr.* Vol. **1**, 1949.
(68) Rosseland, S. *The Pulsation Theory of Variable Stars*. Oxford, 1949.
(69) Rosseland, S. *M.N.* **110**, 440, 1950.
(70) Sauvenier-Goffin, E. *Ann. Ap.* **12**, 39, 1949.
(71) Sauvenier-Goffin, E. *Mém. Soc. R. Liége*, **10**, sér. 4, 1950.
(72) Schatzman, E. *Ann. Ap.* **10**, 93, 1947.
(73) Schatzman, E. *P o. Med. København.* No. 149, 1949.
(74) Schatzman, E. *Contr. I. Ap. Paris*, A, No. 61.
(75) Schatzman, E. *Bull. de la Classe des Sciences*, **35**, 1141, 1949.
(76) Schatzman, E. *Bull. de la Classe des Sciences, Bruxelles*, **34**, 828, 1948.
(77) Schatzman, E. *Ann. Ap.* **12**, 281, 1949.
(78) Schönberg, M. and Chandrasekhar, S. *Ap. J.* **96**, 161, 1942.
(79) Schwarzschild, M. *Ann. Ap.* **12**, 148, 1949.
(80) Schwarzschild, M. and Hen, L. *M.N* **109**, 631, 1949.
(81) Schwarzschild, M. and Richardson, R. S. *Ap. J.* **108**, 373, 1948.
(82) Schwarzschild, M. and Savedoff, M. P. *Ap. J.* **109**, 298, 1949.
(83) Severny, A. B. *Crim. Publ.* **1**, 2, 1948.
(84) Severny, A. B. Chandrasekhar, *Introduction à l'étude de la structure des étoiles*, 194 (l'édition russe).
(85) Sorokine, V S. and Masevich, A. G. *A.J. U.S.S.R.* **28**, no. 1, 1951.
(86) Sorokine, A. I. and Sorokine, V S. *C.R. Acad. Sci. U.R.S.S.* **54**, no. 60, 1946–1947.
(87) Strömgren, B. *Matem. Tidskr.* (Copenhagen), Vol. **96**, 1950.
(88) Struve, O. *Stellar Evolution*. Princeton, 1950.
(89) Sweet, P A. *M.N.* **110**, 548. 1950.

A. Details of papers mentioned by Mrs C. M. Bondi in the Report.

Many of the papers were concerned with stellar evolution. Hoyle (35) suggested that the true stellar model was such that stars just formed consist almost entirely of hydrogen, with only 1% by mass of heavy elements. He supposed the basic stellar material to be hydrogen, heavy elements being synthetized from hydrogen in the cores of collapsing stars (36), cosmic rays being produced at the same time (37). Details of the collapse into white dwarfs were also considered (38, 39) and it was suggested that any hydrogen they possess must have been acquired subsequent to the collapse. The condensation of interstellar matter into stars was briefly considered (40).

Other papers considered stellar models with a lower molecular weight μ in the envelope than in the central regions. Hoyle and Lyttleton (43) established in general terms that a discontinuity in μ can lead to a large radius, such as is needed to explain red giants (cf. Schwarzschild's work, quoted in the main report). Their work was continued by the Bondis, who found (3) that no homogeneous model can adequately explain the red giants, but if photoelectric absorption is dominant (5) infinite radii are theoretically possible with one discontinuity of μ. If electron scattering is dominant, the possible radii are large but not indefinitely great (6). In this work the Bondis made use of a semigraphical method developed by them (4, 2) for rapid approximate integration of the stellar equations; this method employs homology-invariant variables and makes use of the fact that the equivalent polytropic index varies only slowly from point to point.

B. Abstract of a Report from the Japanese National Committee.

H. Simamura (90) has studied the fundamental reactions of positions and protons of high energies with material in the physical state found near the centre of a star.

Y Iinuma (91) has discussed the chemical composition of stars containing helium, using the equation of generation of energy. In a second paper (92) he has discussed the variations of luminosity as a star evolves without change of mass.

S. Ueno and S. Matsushima (93) have considered the dependence of the hydrogen convection zone on the spectral class, taking account of the opacities due to neutral and negative hydrogen.

K. Suda (94) has estimated the relative importance of scattering and absorption in the envelopes of seven Trumpler stars, using Strömgren's mixed opacity law and a modified form of Chandrasekhar's envelope theory.

C. Supplementary Report received from Mme Masevich.

P. P. Parenago and A. G. Masevich (95) examined the Hyades cluster in connexion with the work of Masevich on HR-diagrams in open clusters. A thorough checking of the masses, luminosities and radii for six binaries in that cluster indicates no reason to believe the cluster stars to follow a special mass-luminosity relation, as was suggested by Kuiper.

A. G. Masevich, L. N. Tulenkova and V P Matveeva (96) constructed a stellar model with a convective core and the opacity law $k = k_0 \rho^{0.875} T^{-3.5}$. The model was compared with models with different opacity laws. Comparison with stars actually existing showed that a model with a convective core applies only to main-sequence stars. Even if a discontinuity in chemical composition between envelope and core is allowed for, this model cannot explain the extended radii of giant and sub-giant stars. The paper also shows that even along the first part of the main sequence (O–G stars) a slight variation of the opacity law has to be taken into account. A model with a definite k cannot apply to the whole range from O to G.

https://doi.org/10.1017/S0251107X00032594 Published online by Cambridge University Press

(90) H. Simamura: *Publ. A.S. Japan*, **1**, nos. 1–2, 1949.
(91) Y. Iinuma: *Publ. A.S. Japan*, **1**, nos. 1–2, 1949.
(92) Y Iinuma: *Publ. A.S. Japan*, **1**, no. 3, 1949.
(93) S. Ueno and S. Matsushima: *Publ. A.S. Japan*, **2**, no. 1, 1950.
(94) K. Suda: *Science Report, Tohoku Univ.*, Sec. 1, 35, no. 2, 1951.
(95) P. P. Parenago and A. G. Masevich: *A.J. U.S.S.R.* **29**, 6, 1951.
(96) A. G. Masevich, L. N. Tulenkova and V P. Matveeva: *A.J U.S.S.R.* **28**, 6, 1951

Report of meetings

ACTING PRESIDENT: Prof. T. G. COWLING.

SECRETARY: Dr P. LEDOUX.

First meeting, Monday, 8 September.

After recalling the great loss suffered by the Commission through the death of Pr E. A. Milne, the Chairman opened the discussion on the President's report which w adopted with some additions.

After a discussion of the form of the Report, the Commission passed the followi resolution:

The Commission welcomes the proposal that a Committee be appointed to draw up a co to be followed by Presidents of Commissions in the preparation of their reports.

Dr E. Schatzman withdrew the second and third of his recommendations present at the end of the Draft Report and discussion of the first led to the following resolutio

Dr Marshak should be asked to publish his tables if necessary with the assistance U.N.E.S.C.O. funds available to the I.A.U. for publications.

In regard to the recommendation (*f*) of Dr A. B. Severny, the Chairman stated th the graphs due to Bondi had been printed and were available. In this connexion Dr Bon stated that solutions are being computed on a fairly large scale and that when complet they would be available to members of the Commission on application.

On Severny's recommendation (*e*), it was agreed to ask Dr Trumpler if he could publi his results.

The Chairman then suggested that the problem of red giants should next be discusse

Dr Schwarzschild stated that his impression was that inhomogeneous models wou cover some of the interesting regions in the Hertzsprung-Russell diagram. While earli no models had been found, now there were perhaps too many. Physical processes a evolutionary considerations might help to select the right model. He had studied t extreme case of absolutely no mixing where the progressive burn-up of hydrogen in t core led to a non-static model. Energy released by the ensuing contraction contribut only a few per cent of the luminosity. But contraction takes place only in the core a the envelope dilates, leading to an enormous expansion of the surface.

Dr Bondi then stated that he had confined attention to a more limited class of mod presenting discontinuities fairly far out in the star. A very substantial extension w found quite sufficient to explain any giants that are well known. The earlier objectio that the mass was too small have been largely removed by Struve's work on Capell Discussing how this type of stars could arise, he recalled the initial suggestion of Hoy and Lyttleton where the discontinuity was due to accretion. In regions where no inte stellar matter is present some other mechanism of formation may have to be found.

Replying to a question by Dr Gratton, Dr Schwarzschild drew attention to the wo of Epstein which showed that the new models for red giants led to no further difficulti in connexion with the periods of variable stars. To a question by Mme Masevich, he replied that he had considered only perfect gas conditions at the centre but deviations from these conditions were possible.

Dr van Albada pointed out that it might be an insufficient approximation in a non-static model to suppose that the core was isothermal.

Dr Hoyle said that giants of types I and II seem to originate from stars that initially occupy roughly similar positions on the main sequence. He suggested that type I giants evolve from stars in which there is rotational mixing throughout an appreciable fraction of the mass, say 50%. Type II giants would be stars without rotational mixing which initially have only a small region of high molecular weight, which however gradually increases through some contraction process.

Second meeting, Wednesday, 10 September.

The first part of the meeting was devoted to a discussion of problems arising from the exhaustion of energy sources in the central part of the star.

The discussion was opened by Mme Masevich who made some general remarks on recent work in the U.S.S.R. She pointed out the approximate nature of our information about opacity and energy generation and suggested that at present as many alternatives as possible should be studied rather than concentrating all one's energy on a single one.

Discussing stars with complete mixing, she stated that the evolutionary track of bright stars would leave the main sequence if the mass remains constant and inferred from observations that such stars actually lose mass. She suggested that a star of ten times the solar mass would take $7 \cdot 10^9$ years to reach the mass of the Sun, there being no appreciable changes in luminosity during the last $3 \cdot 10^9$ years.

In the case of no mixing, transformation of H into He in the core could go on until a limiting configuration was reached in which the molecular weight in the core was about twice that in the envelope. During this stage of evolution the changes in the luminosity were insufficient to remove the star from the general dispersion about the main sequence.

A massive star would take only 10^6 years to reach the limiting configuration. The possible modes of further evolution might be either the ejection of material or the passage to a giant state.

Dr Mestel stated that Sweet's work on rotational mixing overestimated the power of the mixing due to this cause. The initial mixing due to rotation will bring about variations of the molecular weight on a level surface which limits the circulation.

Dr Biermann stated that his work on comets suggested that the Sun might have lost a small but not negligible fraction of its mass since the formation of the solar system.

The Chairman suggested that both theoreticians and observers should study the possibility of corpuscular radiation more closely. The possible mechanism should be considered in detail.

Dr Schatzman said that he understood from geophysicists that corpuscular radiation of the type envisaged by Biermann would cause no observable effects in the Earth's atmosphere.

The second part of the meeting was now devoted to problems of variable stars.

In the absence of Prof. S. Rosseland, the Chairman opened the discussion by a few words on magnetic variable stars. He felt that, while the problem was a fascinating one, the difficulties regarding the forces that produce the oscillations and the way in which the oscillations affect the magnetic field had not yet satisfactorily been explained.

Dr Ledoux stated that contrary to his assertion in the Report that the neglect of the perturbation of the gravitational potential in non-radial oscillations might be important, he had now found that this neglect introduces no serious error.

Dr Mestel suggested that stars possessing no static configurations might be able to describe finite oscillations. He had studied such oscillations but the mathematical difficulties were such that a complete discussion would have to wait for electronic calculators. The problem is a non-linear one and no homology relation exists. In cor sequence, stars performing such oscillations would not lie on a curve parallel to the mai sequence.

Dr Bondi suggested that in work on stability a simple discussion might be given i terms of direct energy considerations.

Dr Schwarzschild suggested that if Dr Mestel's ideas were correct, variable sta1 would have to appear much lower in the Herztsprung-Russell diagram than they a1 actually observed.

Dr Schatzman discussed some of the nuclear reactions which may cause vibration; instability and suggested that one of these, involving the reaction $^3He + \beta^- \rightarrow {}^3H$, migh endanger stability in dense stars. He suggested recurrent instability due to this reactio as a possible explanation of novae and SS Cygni stars. A further mechanism leading t ejection of matter was the growth of free waves due to an instability in the envelope c a star.

https://doi.org/10.1017/S0251107X00032594 Published online by Cambridge University Press