35. COMMISSION DE LA CONSTITUTION DES ETOILES

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In the last few years, certain trends already noted in the Dublin report have been accentuated. First, integrations of the equations of stellar structure have increasingly been carried out by electronic computer. This has enabled more accurate information about stellar energy-generation, opacity, etc. to be employed instead of crude approximations. Indeed, so much detailed information has been fed in that occasionally even the resources of a large computer have been taxed to the full. Some recent work has accordingly concentrated on finding simpler methods of carrying out the necessary integrations.

Next, studies of stellar evolution have tended progressively to replace studies of purely static models of stars. This has partly been due to the observations of clusters made by Sandage, Johnson, Walker and others, which have challenged theorists to provide an acceptable explanation. In part, however, the recognition of progressive changes in composition due to nuclear processes in a star has itself compelled consideration of evolution.

The theory of atomic transmutations in stars has accordingly grown to become an integral part of the theory of stellar structure. Theories of the origin of elements are speculative to the extent that they may rest on some preconception about the primeval state of matter. However, investigations as to how nuclear processes in stars can modify the known composition of cosmic material are clearly desirable. Accordingly, a short section of the report will be devoted to this topic.

PHYSICAL FUNDAMENTALS

Opacity, equation of state

The tables of opacities constructed by Keller and Meyerott (as mentioned in the Dublin report) have now been published [1]. A paper giving details of the data on which these tables were based is in process of preparation. The work has been continued by Moszkowski and Meyerott [2], who calculated photo-electric K and L shell absorption for highly ionized atoms, taking electron-screening into account. E. Olson, working with Wrubel, has used data supplied by Keller to compute opacities for a wide variety of relative abundances of the elements; he has derived a programme, available on request, for any I.B.M.-650 computer to calculate opacities. J. Stewart, also working with Wrubel, has used Olson's calculations and recent revisions by Fowler *et al.* of nuclear cross-sections to find interpolation formulae for κ and ϵ more accurate than those so far in use.

Rudkjøbing [3] calculated the Gaunt factor for free-free absorption in hydrogen as a function of ρ and T. Sagdeev [4] has investigated the effects on stellar opacity of Debye screening and of simultaneous interaction of an electron with many ions; the effects have opposite signs and the first is twice as large as the second. Gradusov [5] considered absorption by H and He as compared with that by heavy ions, finding that heavy-ion absorption is not negligible unless $X+Y>0{\cdot}99$. Schmidt, at Göttingen, has investigated the effects of diffraction on radiative transfer in stars, finding that these are important only in conditions such that heat conduction by electrons already dominates the radiative transfer. Radzievsky [6] has discussed the forces arising from radiation pressure, finding that in a star radiation pressure cannot be regarded purely as a tensor.

Kaminishi [7] has calculated the effective polytropic index for adiabatic changes in gases, showing that it is increased both by electrostatic interaction and by radiation. Singh [8] considered the electrostatic correction to the equation of state for white dwarfs and found it to be negligible, as assumed by Stoner and R. H. Fowler.

Energy-generation: atomic synthesis

Salpeter [9] has considered reactions between protons and light nuclei in stars. He was mainly concerned with reactions with D, Li, Be and B, important in very early stages of the star's lifetime, but commented also on reactions of the CN cycle. Heller [10] has considered the origin of the deuterium observed in the Earth and meteorites on the alternative hypotheses of its production (*a*) in the original phase of the expanding universe, (*b*) in super-nova explosions, and (*c*) in synthesis in stellar cores. He concludes that none of these is adequate to explain all the observations. Hayashi and Nishida [11] have also considered the origin of light elements in the original phase of the expanding universe, and are extending their work to consider heavy elements. Shklovsky [12] suggests the origin of solar Li and Be in surface reactions of solar 'cosmic' rays, presumably accelerated by electromagnetic fields.

Reaction-rates for helium-burning reactions in late stages of stellar evolution have been calculated by a number of workers [13]. Cameron [14] has considered neutron-production by reactions of He with nuclei like ^{13}C, ^{17}O, ^{21}Ne. The importance of this for building heavy atoms has been considered in detail by Fowler and G. R. and E. M. Burbidge [15].

The same authors have also considered the possible synthesis of elements in the outer layers of magnetic stars as a result of neutrons produced from protons accelerated in a magnetic field [16]. G. R. and E. M. Burbidge [17] have indicated observational evidence of progressive changes in composition of stellar atmospheres due to this or other causes. Gurevich [18] has considered the possible origin of heavy elements in interstellar matter, by the acceleration of particles during the collision of magnetic clouds.

A number of authors [19, 20] have considered the possible origin of heavy elements in super-nova explosions. Hayakawa, Ito and Terashima are working on the possibility that the most important source of energy of the Crab nebula at present is the radioactive decay of ^{229}Th. Burbidge *et al.* [20] have suggested, on the basis of the decay time of about fifty-five days, that the main part of the energy of a Type I super-nova after maximum comes from the decay of ^{254}Cf, and discuss the possible synthesis of the ^{254}Cf by neutron capture. They suggest that Tc in S-stars is due to a similar, but slow, neutron-capture reaction; Nahmias [21], on the other hand, suggests its generation from ^{99}Ru by a neutrino reaction.

STATIONARY STARS

Models in general

Naur [22] has calculated an extensive set of models of homogeneous stars, based on the P-P reaction ($\epsilon \propto \rho T^4$) with various opacity-laws of the form $\kappa \propto \rho^{\alpha} T^{-\beta}$ ($0 < \alpha < 1$, $0 < \beta < 3 \cdot 5$). This work appears to make further study of similar models largely superfluous. Frank-Kamenetsky [23], comparing a set of calculated pure hydrogen models with observation, concluded that the middle part (A 6–M 0) of the main sequence could be explained by such models with P-P generation of energy; earlier-type stars appeared to demand a different source of energy. Suda [24] considered the properties of a homogeneous model with a convective core, a radiative intermediate zone and a convective envelope; C-N generation of energy and Kramers opacity were assumed. The effect of the convective envelope is mainly to increase the radius for given μ.

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Härm and Schwarzschild [25] considered models of non-uniform composition, with homogeneous core and envelope and an interzone in which μ varies as an inverse power of M_r, generation of energy being either in a convective core or in a shell-source surrounding the star. The main difference from models with discontinuous μ was to give a rather smaller radius. Reznikov [26] calculated a series of models with isothermal cores, radiative envelopes and shell-source generation of energy, the composition of the envelope varying from model to model. He found that if the core is non-degenerate the model can represent only main-sequence stars; if it is degenerate, the model can give stars of large radii, corresponding to part of the red-giant region in the H.R. diagram. Hayashi [27] has studied a similar model, taking into account the effect of ion-pressure in the partially degenerate core, and has obtained similar results. Shimoda and Obi are studying a model with a partially degenerate isothermal core, convective envelope and a radiative intermediate zone. Hitotuyanagi and Suda [28] have constructed models with non-degenerate isothermal cores, a radiative envelope and an intermediate convective zone, a discontinuity in μ occurring at the interface between the core and the convective zone. The models form a continuation of the Schönberg-Chandrasekhar-Harrison sequence.

Henyey, LeLevier and Levée [29] have studied the evolution of a newly-born star contracting on to the main sequence, and drawing its energy supplies from gravitational sources. They found, e.g. that an Ao star on the main sequence would be produced in 3×10^6 years by contraction from an initial state with surface temperature 4000° K. Frank-Kamenetsky and co-workers are developing an iteration method for computing stellar models which, it is hoped, will noticeably shorten the calculations. The method is to be applied in calculating evolutionary models for the Sun and other stars, supposed initially to consist of pure hydrogen. In papers mentioned in the Dublin report [30] Frank-Kamenetsky found that small admixtures of heavy elements may appreciably increase the central condensation; he proposes to allow for their effect by changing from hydrogen absorption to absorption by heavy elements in the outer layers.

Henon, working with Schatzman, has designed an electronic analogue computer specially for stellar structure calculations. This apparatus permits taking into account the exact variation of the absorption coefficient with density and temperature.

Models for the Sun

Abell [31] has published details of his calculations for the Sun, based on P-P generation; as noted in the Dublin report, he failed to obtain agreement with observation for any value of the heavy-element concentration Z. Naur [32] confirmed a suggestion by Abell that the discrepancy between Naur's results and Abell's was likely to be due to slight differences in the assumed opacity laws, to which the model is extremely sensitive.

A further solar model based on the P-P reaction was constructed by Schwarzschild, Howard and Härm [33] with a convective envelope and an inhomogeneous interior. The degree of inhomogeneity was inferred from an initial homogeneous model, assuming hydrogen-burning at the rate required to maintain the present luminosity. A parameter measuring the efficiency of convection of energy in the envelope was regarded as adjustable. A reasonable value of this parameter gave $Y=0.2$ and $Z=0.02$; the corresponding temperatures at the centre and at the bottom of the convective envelope were about 15×10^6 and 10^6 degrees respectively. Weymann [34] improved the model by incorporating effects of the C-N cycle and modifying the method of estimating the degree of inhomogeneity. Even though the C-N cycle provided 36% of the central generation of energy (5% of the total) there was no convective core, and the runs of density and temperature were not greatly affected. Sears, working with Wrubel, is hoping to improve this work by using small evolutionary steps in evaluating changes in μ, and employing more accurate interpolation formulae for κ and ϵ. Ledoux and Mme Bosman-Crespin have also been attempting to improve the work, carrying out inward integrations only. So far they have failed to get physically acceptable solutions near the centre; they hope to elucidate the reason, which does not appear to be any mathematical instability.

Mme Masevich is independently constructing a set of solar models. These consist of three parts, with different chemical compositions: (i) an envelope without energy sources, (ii) an interzone where P-P generation occurs, (iii) a convective core with both P-P and C-N generation.

Models for other stars

Evolutionary models for globular clusters were first studied by Hoyle and Schwarzschild [35] in a paper noted in the Dublin report. Their work was followed up by Haselgrove and Hoyle in two papers [36]. The first of these described a scheme for programming the computations for an electronic computer. The effects of conduction, convection, various kinds of opacity, hydrogen and helium-burning, gravitational contraction, relativistic and non-relativistic degeneracy were all included. Logarithms of the physical variables were used in the computations, so that subsidiary calculations were needed for the regions near the centre and the boundary. In the second paper the programme was applied to calculate evolutionary models for a star of mass $1 \cdot 3 M_{\odot}$ evolving up to the tip of the cluster giant sequence. Hoyle has since been working to extend this work to the more advanced phases in which hydrogen and helium are burning simultaneously. Schwarzschild and Selberg are similarly studying advanced phases, using a fully automatic technique. Obi [37] has computed a number of models with a double energy-source, due to helium reactions in a core and hydrogen-burning in a shell round the core. The masses concerned were in the range 1–$1 \cdot 4 M_{\odot}$, and the models gave reasonable agreement with the horizontal branch of the cluster H.R. diagram.

Tayler [38] considered the initial evolution of early-type stars, assuming energy-generation in a convective core, and Kramers opacity; as hydrogen in the core is burnt, the core shrinks and a transition zone of variable μ appears outside the core. The models cover a range in which about one-ninth of the star's hydrogen is burnt, and the radius is about doubled. Kushwaha [39] carried out similar computations for stars of mass 10, 5 and $2 \cdot 5 M_{\odot}$, using a combination of electron-scattering and Kramers opacity, and taking into account energy-generation outside the core; the latest phases studied showed a kink in the H.R. diagram due to a reversal of the initial decrease of surface temperature.

Härm and Rogerson [40] computed two models for early-type stars, one assuming only electron-scattering and the other Kramers opacity. The apsidal-motion constants were calculated for each; to get agreement with observation for B stars, electron-scattering had to be taken into account. Schwarzschild and Härm are studying the early evolution of stars of great mass (30–$200 M_{\odot}$). A feature is the unexpected appearance of a semi-convective zone in which the gradient of μ adjusts itself to make the zone convectively neutral.

Aron [41], working with Keller, has attempted to construct a model for η Aqu incorporating H and He convection zones, so far with incomplete success. When a satisfactory model is derived, it is hoped to study its pulsational properties.

Limber at Princeton has been studying completely convective models for late M dwarfs. After a rediscussion of the relevant bolometric corrections, these models are found to fit the observations very satisfactorily.

Schatzman [42] has considered the effect on the internal structure of white dwarfs of nucleon-electron equilibrium. The capture of electrons increases μ_e and implies (*a*) a maximum mass when the radius exceeds a critical value R_n, (*b*) dynamical instability of models of radius less than R_n. Kaminishi [43] has studied a number of properties of white dwarfs, such as their tidal distortion and gravitational energy, and the effect of ion pressure on their internal structure. He estimates the lifetime of these stars from their gravitational energy, and concludes that they can rapidly evolve from stars near the earlier main-sequence region of the H.R. diagram. Masani [44] considers the birth of white dwarfs, showing that a star of mass less than $\frac{1}{4} M_{\odot}$ could contract to a degenerate state without ever being able to generate energy by thermo-nuclear reactions.

Rotation, internal currents, etc.

Kippenhahn [45] has considered the effects of rotation on the standard model, in a zero-order approximation in which the rotation is so slow that the radiative transport of momentum is the only factor which has to be taken into account, meridional currents being negligible. His results indicate a much faster rotation near the centre than near the boundary. He is now working on a first-order theory in which the circulations are found and their reaction on the law of rotation is treated as a linear disturbance. Porfirjev [46] has given a first-order theory of the effects of rotation on an early-type star, using Rudkjøbing's model as zero approximation. He found that rotation increases the mass and radius of the model, but by amounts less respectively than 20 and 10%. Armellini [47] showed that the maximum density in a rotating polytrope of index n must exceed $(n+1)\omega^2/2\pi G$.

Biermann [48] showed that in general a state of pure rotation (without internal circulation) is not a possible state of steady motion in the convective zones of stars (a result of interest in connexion with the theory of migration of sunspot belts). Also, replying to a suggestion by Schmeidler [49] that convection might spread from an unstable zone to engulf a whole star, Biermann and St. Temesváry [50] pointed out that convection in a stable region can be maintained only by an impossibly large import of mechanical energy, and is unlikely to be significant.

Mestel [51] has considered meridional circulation due to rotation in shell-source stars, using the methods which he previously applied to the point-convective model. He found that mixing between the energy-generating region and the rest of the star is even smaller than with the earlier model.

Sandage [52] has attempted to derive from the observed rotations of giant stars their rotations before evolving off the main sequence. Two alternative hypotheses were used: (i) the angular momentum for the whole star is conserved, the star rotating uniformly at any instant, (ii) the angular momentum of the surface layers is conserved. The results agree reasonably well with those for existing main-sequence stars for hypothesis (i), less well for hypothesis (ii).

Pike [53] calculated apsidal-motion constants for a variety of models. To get agreement with observation for Y Cyg, he found it necessary to use a model inhomogeneous in composition.

NON-STATIONARY STARS

Novae, flare stars, etc.

Much of the work done on the theory of novae has in fact been a study of the propagation of shock waves in stars. As such its interest has often tended to be mainly aerodynamical; I shall content myself with giving reference to certain of the papers concerned [54]. McVittie and Rogers [55], in an investigation of a shock-wave super-nova model, found that for any particular degree of central condensation the central temperature must exceed a minimum value for an explosive emission of energy. The energy-loss for a central temperature of 2×10^7 degrees is of order 10^{50} erg.

Gurevich and Lebedinsky [56] explain nova explosions in terms of instability at a transition from nuclear energy-generation to gravitational contraction. Mme Masevich [57] considers that they may result when hydrogen exhaustion in a convective core is followed by a partial internal collapse, with a release of energy that leads to a mixing of the whole star; for a star of mass $25M_\odot$, explosions may occur at intervals of about 10^4 years. Petukhov [58] explains unsteady behaviour by nuclear processes in stellar interiors, particularly by the building of a Li-enriched core. Schatzman [59] suggests that nova phenomena may be associated with resonance in a close double star; this leads to a theory of recurrence which avoids difficulties met in an earlier attempt.

Frank-Kamenetsky, in collaboration with a group of mathematicians, plans to study the evolutionary changes after exhaustion of He in the core of a star on the horizontal branch of the cluster H.R. diagram. He believes that at the boundary of the core powerful shock waves may develop which may either excite oscillations or lead to explosions. In this connexion one may recall Greenstein's result [60] that the recurrent nova WZ Sge appears to be in transition to a white-dwarf state.

Gandelman and Frank-Kamenetsky, in continuation of earlier work [61], are trying to explain flares in T Tau and UV Cet stars by shock waves originating in sub-photospheric convective layers.

Pulsations and stability

Counson, Ledoux and Simon [62] have re-evaluated the effect of molecular viscosity on radial and non-radial oscillations. Though the high proportion of hydrogen increases the viscosity very considerably above values used earlier, the damping times of the first four modes remain too large to be significant. However, turbulent viscosity may increase the rate of damping greatly. Cox [63] and Rabinowitz [64] both determined the rate of stimulation of stellar pulsations by thermo-nuclear reactions and the rate of damping by radiation. Their numerical values, referring respectively to a radiative giant model and to one with a convective envelope, differed considerably, but agreed in indicating that thermo-nuclear stimulation is negligibly small compared with radiative damping. Simon [65], in a similar study of non-radial oscillations, showed that the stability was greater for these than for radial oscillations.

There remains the possibility that the stimulation of vibrations is, as Eddington suggested, due to properties of a convective outer layer. Schatzman [66], using a red giant model constructed by Mme P. Curien, was able to confirm this suggestion. He found the model to be vibrationally unstable—the first such model to be identified. Krogdahl [67] had considered finite oscillations of a star and the problem of their self-excitation, but reached no very precise conclusions.

In three papers, Simon [68] has studied the propagation of waves of small amplitude through a star, giving explicit analytical solutions in certain cases. When perfect reflexion at the surface is assumed, the usual eigen-frequencies are recovered; when reflexion is imperfect, phase lags can be studied with precision. Schatzman [69] has studied pulsations of a composite atmosphere, to determine the exact boundary conditions in the atmosphere and the extent of damping by progressive waves. Dmitriev, Feodoritova and Frank-Kamenetsky [70] constructed a solution of the equations of non-adiabatic pulsation in a star, assuming a constant adiabatic index. Whitney [71] has shown that in some cases the transfer of momentum due to the propagation of finite waves through a stellar atmosphere leads to a decided increase in the mean scale height, and found that the observations for W Vir are compatible with an atmospheric shock front travelling with uniform velocity. For η Aqu, Ledoux and Grandjean [72] determined theoretical radial-velocity curves at different levels in the atmosphere, considering particularly the possible distention of the outer layers through convection; the curves obtained were compatible with the observations.

Ledoux *et al.* [73] have studied the effect on the periods of stellar pulsation of an extensive external convection zone. Both the fundamental period and its ratio to the period of the first overtone are increased; the latter ratio may be able to take the value 2, in which case coupling between the oscillations would be possible. Whitney and Ledoux [74] have reduced the determination of the eigen-frequencies for radial pulsation to the solution of a set of linear equations by treating the star as composed of a number of discrete but interacting shells; a first test of their method has yielded encouraging results. Simon [75] has shown that in an infinite atmosphere in which the density decreases as $r^{-\alpha}$ ($\alpha > 3$) no standing oscillation is possible; but that in the generalized Roche model (homogeneous core + tenuous envelope) eigen-solutions are always possible (contrary to an earlier conclusion of Kopal) if the boundary conditions across the surface of the core are correctly taken into account. Owen [76] integrated the differential equation of non-radial oscillations for polytropes of index 3·25, 3·5 and 3·75; he found that the lowest harmonics disappear one after the other as the polytropic index increases.

MAGNETIC STARS

In a large proportion of the theoretical work which has been done on magnetic stars, a uniform incompressible liquid star has been assumed. This assumption is demanded for mathematical simplicity. Care must, however, be taken in applying the results, since the properties of real stars may be altogether different from those of the models. The models can be in equilibrium only for special forms of the magnetic fields, because of the neutral stability of a uniform liquid mass to purely internal displacements. On the other hand, Mestel [77] has shown that in a real star, because of its internal stability, any moderate-sized field is consistent with virtual equilibrium.

A number of papers [78] have dealt with the distortion of a liquid globe by an axi-symmetric field whose lines of force lie wholly in meridian planes. Some of these have used an energy method; this is often useful when only a rough value for the distortion is desired, but has been found to be dangerous when a manifestly non-equilibrium field is used or (because of an external magnetic field) the total magnetic energy is infinite. In the latter circumstances a method based on the exact equations of equilibrium and boundary conditions is preferable.

Lüst and Schlüter [79] and Chandrasekhar and Kendall [80] have discussed force-free fields, in which the electric currents flow everywhere along the lines of magnetic force. Such fields were invoked by Lüst and Schlüter [81] to explain the magnetic braking of stars; the field transmits angular momentum out to a point where turbulent transport by the interstellar medium is able to take over. Chandrasekhar and Prendergast [82] found a general form for an axi-symmetric field consistent with equilibrium in a liquid mass, and Prendergast [83] identified a particular field of this type which leaves the boundary spherical. A similar field in a rotating mass was studied by Sykes [84].

Chandrasekhar [85] gave general equations of motion for axi-symmetric fields and flows and applied them to study the effect of axi-symmetric motions on the decay of magnetic fields. His result, that such motions can slow down the rate of decay almost indefinitely, appears, however, to rest on faulty approximations, since the rate of decay must always exceed a certain minimum value [86]. Chandrasekhar [87] has also applied his equations to study the stability of a particular class of motion, in which the flow is everywhere along the lines of force.

A number of papers [88] have discussed toroidal oscillations of magnetic stars, chiefly in connexion with theories of sunspots and magnetic variables. Plumpton and Ferraro showed that the periods of oscillation were not a discrete set, but continuous; Stewartson showed that this state of affairs is not affected by dissipative effects. Jensen found that a decay field in a liquid sphere is unstable to toroidal displacements; this conclusion is, however, open to criticism, since a decay field is not itself consistent with equilibrium of the sphere. Ledoux and Simon [89] have used perturbation methods to estimate the effects of a weak magnetic field on the frequencies of stellar oscillations.

Deutsch [90] considered the magnetic field of a rigidly rotating star *in vacuo*, showing that the field changes from a rotating field at small distances to a radiating field at large.

COSMOGONY AND EVOLUTION

Birth of stars

Ebert [91], Bonnor [92] and McCrea [93] have considered star formation by the gravitational collapse of an isothermal gas cloud. Ebert and Bonnor both regarded the initial state as an Emden isothermal sphere; they discussed the instability problem in totally different ways, but their estimates of the least mass required to produce instability in a cloud of given density agree as regards order of magnitude. McCrea, discussing the same problem by cruder methods, suggested that the process will operate in less highly idealized conditions than those assumed by Ebert and Bonnor. Ebert [94] earlier found conditions for gravitational contraction in an isothermal H I cloud compressed by an expanding

H II region (the Oort-Spitzer process). McCrea similarly regards the initial contracting cloud as compressed by the Oort-Spitzer process. However, since instability demands masses some hundreds times the mass of the Sun, he is now working on a hypothesis that the first contraction produces an unstable transient 'star' which soon blows itself to pieces; the pieces are then able to collapse by the same process taking place at much greater densities, to produce stars of normal mass. Savedoff and Greene [95] have similarly considered star production through instability due to an expanding H II region, but they regarded the compression leading to instability as due to a violent shock wave moving in advance of the ionization front.

Such developments are closely linked to Ambartsumian's ideas on stellar systems of positive energy, which, with their cosmogonic implications, he has further expounded [96]. The same is true of Fesenkov's result [97] that the possibility of close star chains originating by a random process is so remote that stars of the chain must be regarded as having a common birth. Fesenkov considered gas-dust clouds, as did Lebedinsky [98] in an account in which stars of mass up to $5M_{\odot}$ were regarded as produced by gravitational collapse, more massive stars by accretion.

Idlis [99] estimated the smallest possible mass of a star as about $0{\cdot}005M_{\odot}$, by comparing the energy of interaction of electrons and protons in the star with the gravitational energy.

Mestel and Spitzer [100] considered the mode of formation of stars in a magnetic gas cloud, the difficulty being to avoid an increase in magnetic pressure sufficient to prevent further contraction. They suggest that, as the optical thickness of the cloud increases, the temperature and ionization will decrease to such an extent that the lines of force can largely disentangle themselves from the cloud. Pursuing similar ideas, Mestel is considering the origin of a star's magnetic field from galactic fields, and the way in which the lines of force of the star's field become broken off from those of the galactic field.

Dodd [101] considered the possibility of binary formation by one star capturing another in an accreting cloud. He found, however, that such large increases in mass were required for capture that he preferred to regard the capture as occurring at the birth of the stars, while they were still in a dense cloud.

Hagenow [102] used v. Weizsäcker's equations to discuss, in a two-dimensional model, the growth of a condensation in a turbulent cloud. Applications to the origin of a star of solar mass or to a cluster like M 31 were considered.

Changes in mass

McCrea [103] resolved a difficulty in the theory of spherically symmetric accretion, that there is apparently only one possible rate of accretion from a cloud of given density and temperature, irrespective of the degree of difficulty of the final capture of material by the star. He showed that, if the star cannot capture material sufficiently fast, a stationary shock front surrounds the star, and limits the rate of inflow. Danby and Camm [104] considered the dynamics of accretion in the non-spherical case; ignoring collisions of particles before reaching the accretion axis, they found densities on that axis too low to permit substantial accretion. The assumption of negligibly few collisions requires further analysis. Stephenson [105] showed that accretion of dust is largely prevented by radiation pressure of the accreting star. Idlis [106] gave a critical discussion of the whole accretion process, concluding that it cannot lead to the production of a very bright star. Safronov [107] investigated the change in rotation of the Sun produced by the infall of matter due to the Poynting-Robertson effect.

On the observational side Böhm [108], from a study of the brightest Herbig-Haro object, concluded that the temperature of the outer H II region was too high to permit substantial accretion through this region to be the cause of its emission. Hoyle [109] suggested in reply that H I and H II clouds might interpenetrate here. Blackwell and Dewhirst [110] gave arguments strongly suggesting that, whatever the truth of the accretion hypothesis in general, accretion could not be responsible for the solar corona.

The well-known hypothesis that in a close double star a vastly distended giant may steadily lose mass to a more compact companion was supported in papers by Crawford and Kraft [111]. However, Kopal [112] has objected to this hypothesis that it is regularly the secondary which is observed to be at its Roche limit; one would have expected the primary to develop into a giant first.

Deutsch [113] has given a further example of a binary apparently losing mass to outer space. No fresh detailed theoretical work on the mechanism of evaporation of matter from stars has been done; this is unfortunate, for the topic is as important as it is obscure. Van den Bergh [114] has suggested that the supply of interstellar gas for star-building is provided by the ejection from the galactic nucleus of gas ejected from evolving stars.

Evolution

Salpeter [115] has constructed a luminosity function for main-sequence stars when first created, on the assumptions that stars have been created uniformly near the Sun for 5×10^9 years, and that they move off the main sequence after burning 10% of their hydrogen. He found that most of the mass of present-day stars must at some time in the past have belonged to massive stars. Sandage [116] determined a similar primitive luminosity function for galactic clusters and for M 3. Both Salpeter and Sandage assumed constant mass during most of the evolution; each suggested that relics of very massive stars must be found in large numbers of white dwarfs. Sandage [117] used his results to construct semi-empirical evolutionary tracks for stars of M 67 and M 3. He obtains rough agreement with the theoretical results of Hoyle and Schwarzschild, save that at the tip of the giant series the latter indicate a too rapid evolution for the density of stars actually observed.

Mme Masevich [118], on the other hand, contended that the observed luminosity function could be obtained, assuming origin of stars in O-associations, only for an evolution down the main sequence with decreasing mass. She determined evolutionary paths for two main-sequence stars of types O7 and B3 [119]. The evolution is first down the main sequence, the star remaining well-mixed and continually losing mass. After the mass has decreased to about $3M_{\odot}$ total mixing ceases, and the star branches off the main sequence. In a series of papers [120], she also considered the evolution of various clusters and associations. For the Pleiades and Hyades she found that early stars have evolved without mixing off the main sequence, with loss of mass if rapidly rotating, in about 10^7 years for the Pleiades and 3×10^8 years for the Hyades. The brightest stars in associations are asserted to be still in process of contracting on to the main sequence. The differences between the nucleus and the surrounding association for the double cluster h and χ Persei lead to the conclusion that the formation of stars in the association went on for a considerable time after ceasing in the nucleus. The evolution of sub-giants was also considered [121]; these are regarded not as unmixed stars which have evolved off the main sequence, but as distinguished from main-sequence stars simply by an abnormally large proportion of heavy elements. Ruben and Mme Masevich [122] investigated evolutionary sequences for stars not on the main-sequence, using a model with a convective core, and constant or decreasing mass, considering in particular the effect of varying the proportion of heavy elements and the constant ϵ_0 in the energy-generation law.

Taketani, Hatanaka and Obi [123] proposed a scheme of evolution according to which population I stars with high proportions of heavy elements are generated from interstellar matter derived from the super-nova explosions of the older population II stars.

In conclusion, members of the commission may care to know of two books shortly to appear. These are *Theory of Stellar Structure and Evolution*, by M. Schwarzschild (Princeton Univ. Press); and *White Dwarfs*, by E. Schatzman (North Holland Publishing Company).

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President of the Commission

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Report of Meeting. 19 August 1958

ACTING PRESIDENT: M. Schwarzschild.

SECRETARIES: P. Ledoux and Mme A. G. Masevich.

In the absence of Prof. T. G. Cowling, President of the Commission, Prof. M. Schwarzschild, who had been appointed Acting President by the Executive Committee, presided over the meeting.

The Commission decided to send a letter to Prof. Cowling expressing the deep regret of all members that he could not be present. The *Draft Report* was adopted as submitted by the President. After a short discussion the Commission decided unanimously to support the recommendation of the Presidents of Commission 29 and 35 to establish a new commission on magneto-hydrodynamics and the physics of ionized gases.

Dr Bondi emphasized the importance of measurements in the ultra-violet to establish more accurately the bolometric correction for early-type stars. Dr Masevich and Prof. Schwarzschild were urged to influence as much as possible the satellite efforts in their respective countries in this direction.

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Invited reports were given by five members of the Commission and two nuclear physicists as follows. Dr Cameron reviewed the present state of the proton-photon reaction and Dr Fowler did the same for the carbon cycle. Prof. Hoyle described the serious difficulties encountered with present methods for the derivation of evolutionary model sequences with electronic computers, especially at those phases in which the contraction is rapid. Dr Masevich gave a short account of work in progress on solar models with electronic computers. Dr Biermann described electronic computations just finished at Göttingen for red giant models with special attention to the sub-photospheric convection problem. Dr Schatzman suggested a new explanation of SS Cygni stars involving resonance between the revolution of a double star and an oscillation in a non-radial *g*-mode. Prof. McCrea gave a short review of present ideas regarding the formation of population I stars.