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29*a*. SOUS-COMMISSION POUR LA THEORIE DES ATMOSPHERES STELLAIRES

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MEMBRES: L. H. Aller, Barbier, Biermann, G. Burbidge, Mlle Busbridge, Goldberg, Hagihara, Henyey, Hitotuyanagi, Houtgast, Kourganoff, Mme Petrie-McDonald, Mezel, Minnaert. Miyamoto, G. Münch, Mustel, Neven, Pecker, Plaskett, Rudkjøbing, Sobolev, Spitzer, Strömgren, R. N. Thomas, Mlle Underhill, Unsöld, Wrubel.

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INTRODUCTION

Commission activity between the assemblies. Because of the rapid development of the branch of science covered by this Sub-Commission, the desire was felt to increase the contact between commission members, and to exchange ideas more frequently than is possible with our triennial assemblies. To that aim two small colloquia have been organized by the Sub-Commission, one on 3–4 July 1959 in Brussels, on 'The empirical determination of stellar photospheric structure' (*Comm. Obs. Roy. Belgique* **157**, 1959), the other one on 3–5 September 1960 in Meudon on 'Profiles of spectral lines' (*Ann. Astrophys.* **23**, 1960). In organizing the colloquia, very effective help was given by the commission members Neven (1959) and Pecker (1960). The success of these colloquia may partly be due to the fact that they were kept informal, limiting the participation to active workers in the field, and urging them to communicate *problems* and unfinished work rather than *results*; and also because an attempt was made to reserve much time for discussions.

Other colloquia or congresses partly or wholly dealing with the theory of stellar atmospheres (but not organized by the Sub-Commission) were:

(*a*) the 'First plenum of the commission on the physics of stars and nebulae', which met in Lvov (Soviet Union) on 17–19 June 1959 (*cf.* Gorbatsky, 1960);

(*b*) the colloquium on 'Stellar models and stellar evolution', held in Liège, 6–8 July 1959;

(*c*) the colloquium on the 'Ultra-violet spectra of celestial bodies', held in Liège, 11–14 July 1960;

(*d*) the IAU-IUPAP symposium on 'Dynamical problems of stellar atmospheres', held in Varenna, 17–30 August 1960.

In the beginning of 1960 two small working groups were established with the instructions: (*a*) to accelerate the mutual exchange of existing electronic computing programs and to stimulate international co-operation in the use of large electronic machines, in the domain of the theory of stellar atmospheres (chairman: M. H. Wrubel);

(*b*) to examine, in co-operation with Commission 3, the various existing systems of astrophysical notations in the field of the theory of stellar atmospheres, and to propose a common system of notations, to be discussed at the Berkeley meeting of the IAU (chairman: M. Rudkjøbing).

Review papers and books. We refer to Barbier's paper (1958) and to that of Goldberg and Pierce (1959) in the *Handbuch der Physik*, to Miss Busbridge's monograph (1960), to Pecker and Schatzman's textbook (1959), and to Athay and Thomas's book (1961) on the solar chromosphere.

MODELS OF STELLAR ATMOSPHERES

Radiative equilibrium. Sobolev and Minin (1958, 1959) studied the diffusion of radiation in a plane-parallel atmosphere for an arbitrary distribution of the sources. Ueno (1958, 1959, 1960) treated for a number of cases the transfer of radiation in an atmosphere on the basis of the 'probabilistic method': the multiple scattering of photons is of the Markovian type. Unno and Yamashita (1960) developed a method to construct a non-grey atmosphere, without starting from an initial grey model. We also draw attention to the method Krook-Pecker (1959).

Convection and 'turbulence'. The Varenna symposium, August 1960, on aerodynamics of stellar atmospheres was very important. The increased interest in these phenomena in the last three years is partly a consequence of the realization that the convection zones of stars are the region of origin of a field of pressure waves (*not* of turbulent motions in the strict hydrodynamical sense) which, in propagating outwards may lead to a chromosphere or corona (*cf.* review by Biermann, 1959). Böhm-Vitense (1958) computed the structure of the hydrogen

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convection zones of different kinds of stars on the basis of a mixing-length theory. That the mixing-length theory is approximately correct is shown by the reasonable agreement between theory and observations for the Sun (Biermann *et al*, 1959; de Jager and Kuperus, 1961). Clearly, however, the mixing-length hypothesis is rather rough and should be replaced by a more precise one; this problem was investigated by Böhm and Richter (1958, 1959, 1960), Unno *et al* (1960); the final answer has not yet been given, but it has been made clear that the observed diameters of the granulation elements are related to the thickness of the region of maximum instability (Böhm, 1958). For the spectrum and energies of the photospheric 'turbulence' see also Schmeidler (1959) and Shimooda (1960).

When the energy of the pressure waves exceeds a certain limit, they transform into shock waves. These waves have been the subject of investigations by Kaplan and Kliminshin (1958, 1959), Kubikovski (1959), Odgers and Kushwaha (1959), Ono *et al* (1960); whereas the interaction of shock waves with magnetic fields is treated by Pacholczyk (1960); for magneto-hydrodynamic problems see also Dungey's excellent book (1958).

According to Böhm-Vitense's computations *convection* occurs only in stars later than spectral type A; still, random motions occur also in earlier-type stars (see review by Underhill (1961)). These random motions could originate as a consequence of the meridional circulation due to the stellar rotation (Kippenhahn, 1959).

The thickness of the solar convection zone is of importance for the abundance-ratio of heavy to light atoms (example: the Pb/Si ratio), so that the photospheric abundances do not exactly reflect the abundance ratio in the primordial matter from which the Sun originated (Chapman, and Aller, 1960).

The influence of photospheric inhomogeneities on the Fraunhofer lines was discussed by Hubenet (1960) and at the Meudon colloquium (Cuny *et al*, 1961; Delbouille *et al*, 1961).

Chromospheres and coronas, *extended atmospheres*, *mass loss*. The temperatures and densities of stellar coronas were estimated by de Jager (1960), assuming the coronas to be due to the outward propagation and dissipation of mechanical energy from the stellar convection or instability zones. The theory was refined later for the solar corona (de Jager and Kuperus, 1961). The heating of the solar chromosphere by compression waves was discussed by Dubov 1960); who could also show that magneto-hydrodynamic dissipation is unimportant as compared with dissipation of shock-wave energy.

The theory of loss of matter by coronal 'evaporation' (escape of fast particles from the tail of the Maxwellian distribution curve) was given by Rubbra and Cowling (1960); with this theory the mass loss of different types of stars was computed by de Jager (1960).

The computed mass loss for early type stars is still smaller than the observed values (Deutsch, 1959, 1961). This may either be due to an incompleteness in the actual coronal theories, or in the theory of the mass loss. The correct solution for this latter phenomenon may be found in Parker's theory of the solar wind (1958, 1960, 1961); see also Weyman (1960). Wilson's suggestion (1960), that *La* radiation pressure caused by a chromosphere of 10^4 °K may be the cause of mass loss in M stars, does not seem sound; precisely for M stars the theory of coronal evaporation does *not* offer difficulties and yields a sufficient mass loss.

LINE PROFILES

Review papers were written by Unsöld (1958; George Darwin Lecture), and by Pagel (1960). The Meudon colloquium on 'Profiles of spectral lines' has been mentioned. The three crucial matters are: the intensity in the line profiles, especially the cores, are often greatly affected by deviations from Saha's and Boltzmann's law; the line profiles may be affected by redistribution

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('non-coherent scattering'); for most lines the damping constants (or, more generally, the broadening parameters) are badly known or not at all. Since in any case the damping constants and the deviations in the level populations are functions of the optical depths, it is clear that the *analytical* computation of line profiles has grown extremely complicated. One has to be content with a number of serious mathematical approximations which, as a rule, make the problems physically uninteresting. On the other hand modern electronic computers allow anyone who so desires to compute line profiles with nearly any degree of completeness.

For that reason the present compiler would like to propagate a more intensive use of such machines, while the analytical method should be reserved for those problems for which they are apt: the principal use of the analytical method is to clarify our insight into the various physical processes that are important for a certain problem, and to see them rapidly in their correct relation and relative importance.

L.T.E.-problems. The population that a given atomic level will assume in a statical equilibrium is a consequence of the various kinds of transitions (radiative and collisional) to and from that level. So the atomic level populations can be computed as soon as transition probabilities and collision cross-sections and the local radiation field, particle density and kinetic (electron) temperature are known. On the other hand the local radiation field is determined by the population of the various levels—not only by the *local* populations but by those throughout the whole atmosphere, reduced by absorption underway. So the population problem consists of a simultaneous attack on the problem of the statistical equilibrium and of the radiation transfer.

So far two ways have mainly been followed: on one hand one has tried to solve the statistical equilibrium problem for a many-level atom (see Kogure, 1959; Pottasch and Thomas, 1959, 1960; Athay and Johnson, 1960, 1961; Jefferies and Thomas, 1960; Krat and Sobolev, 1960; de Jager, Kanno and Neven, 1961; Kanno, 1961); on the other hand the transfer of radiation has been discussed, by assuming a simplified level scheme, (often reduced to only two or three levels), or by assuming complete balance in the Lyman lines, etc. (see next section).

It is obvious that deviations from the L.T.E. populations and the L.T.E. radiation field will mainly occur in stellar *chromospheres* and coronas, but in the last years Pecker *et al* have found observational arguments for deviations in the solar *photospheric* level populations (Kandel, 1959; Pecker and Vogel, 1959, 1960; Pradérie-Eugène, 1959, 1960; Rountree, 1959, 1960). The deviations from Boltzmann's law in the photosphere are mostly smaller than a factor 2, but the corresponding differences in the deduced chemical abundances may amount to a factor 5. Doubt as to the reality of these deviations has been expressed by Unsöld (1958) and Aller (1959).

Departures from L.T.E. in the H^- continuous photospheric spectrum seem unimportant (Pagel, 1959, 1960).

Transfer of radiation in spectral lines; the source function. Sobolev (1958) and co-workers (Zvonareva, 1958) studied line profiles for different cases (coherent, incoherent scattering; variable ratio of continuous and selective absorption coefficients). We also refer to Ueno's (1958) series of papers on the 'probabilistic' method. Problems of line profiles in moving atmospheres were discussed by some authors (Kanno *et al*, 1958; Sobolev, 1959; Kaplan *et al*, 1960).

In a series of papers closely related to the subject treated in our preceding section Thomas and Jefferies examined the source function for different cases, but *all* referring to resonance lines (see references, also those for the preceding section). The method is analytical: the atomic level scheme is approximated by an equivalent two-, three- or four-level atom; the

M

source function is then determined by the population ratio of the two levels between which the transition takes place. The transfer of radiation is treated by Eddington's approximation. For that case it could be shown that in the classical expression for the source function the 'absorption-term' should be replaced by two other terms depending on whether the absorption of the light quantum takes place by a collision of the second kind or via the intermediary of a photo-electric ionization. Thereby it could be assumed, following Henyey and Thomas, that because of Dopplerian redistribution the source function is frequency-independent up to at least some Doppler widths from the line centre. The problem has been worked out for different cases; one of the main results is the striking difference in behaviour of the source function for lines of the 'photo-electric', 'collisional' or 'scattering' type. The double inversion of the photospheric H and K line cores can be explained as reflecting the variation of the source function with τ. The theory was applied by Morton and Widing (1961) to the core of the solar $L\alpha$ line profile.

Attention is further drawn to the thesis of Hubenet (1960), who computed equivalent widths for different photospheric models and found that the maximum differences are mostly smaller than 50%. Greater errors arise presumably from our poor knowledge of oscillator strengths or from deviations from the L.T.E. population.

Electronic computer programs have now been developed in many observatories; we refer to papers by Cayrel (1959), Chadeau (1961), Schmalberger and Wrubel (1961).

Broadening of spectral lines. A book on the theory of collisional broadening of spectral lines was published by Traving (1959).

Much attention has been paid to the hydrogen lines. Kolb's initial theory, in which the statistical broadening by the ions and the collisional-type broadening by electrons is combined, was compared to the observations and confirmed by Aller and Jugaku (1958) and Van Regemorter (1959). A more refined theory (Griem, Kolb and Shen, 1959, 1960) appears to involve only small corrections as compared to the first version; it still agrees with the observations (Jugaku and Aller, 1960). Cayrel and Traving (1960) showed that for the solar Hα line resonance broadening is comparable in importance with Stark broadening. Underhill and Waddell (1959) computed the displacements and intensities of the Stark components of the H lines arising from transitions between lower levels 1 . . . 4 and 2 . . . 18. De Jager (1961) computed Stark-broadening parameters for these lines. See for the high hydrogen lines Jefferies (1960) and Houziaux (1961).

We further refer to a paper by Cl. Chadeau on the Stark effect for He lines (1959), and to one of Hindmarsh (1959) on the Ca 4227 Å resonance line.

For the analysis or computation of the profiles see papers by Kononovitch (1959) and Posener (1959).

MODEL ATMOSPHERES

General investigation of special models and their spectra. Grey model photospheres with a high helium abundance ($H/He = 0{\cdot}1$) have been computed by Osawa (1959). The continuous spectra appear to be the same as those of 'normal' photospheres with a three times greater acceleration of gravity. Van Regemorter (1959) computed stellar models with different T_0, and g values/and with different $T(\tau)$ gradients. Stellar classification according to the Balmer discontinuity D and the blue gradient φ_b appears to be equivalent to classification according to D and the equivalent width W of H γ, where W was computed with Kolb's first theory. Moreover, these results yield the same g-values as are obtained when using the Mass-Luminosity law with Rigal's new absolute magnitudes. It was found that main-sequence stars are in radiative equilibrium.

Saito and Uesugi (1959) have computed ten photospheric models of stars with effective temperatures between 10 700° and 41 700° (Rosseland mean).

Vardya and Wildt (1960) showed that in models of late-type stars the influence of H_2 molecules must be taken into account.

De Jager and Neven are repeating their earlier investigation of 50 model stellar photospheres, but this time for 60 models ($4000° \leqq T_0 \leqq 35000°$; $1 \leqq \log g \leqq 5$); furthermore the earlier computations of the $H\gamma$ and $H\delta$ profiles were made again but this time for the new Kolb-Green-Shen theory.

Continuous spectra. The 'hump' in the relative energy distribution in stellar spectra, found by Chalonge and co-workers near 4800 Å was attributed by Van Regemorter (1959) to C absorption (thus requiring a rather high C abundance), but by Unsöld (1960) to the increasingly crowded lines in the blue and violet parts of solar-type spectra. Kienle (1960) disagrees with this latter conclusion.

Analysis of individual spectra. A summary of stellar spectra under investigation was given at the Uccle colloquium by de Jager (1959). Among the discussions of the many other normal stars mentioned in the references we may particularly stress the work of Aller and Jugaku (1959) on γ Pegasi, and Hunger's (1960) work on the normal A0 star α Lyrae, which does not show abundances different from these of the Sun. Aller, Boury and Jugaku are well underway with the stars 114 Tau, 22 Ori, HD 36959, HD 36960, 15 CMa and ξ CMa (*Ap. J.* 1961).

Population II stars: Baschek (1959) analysed the *sub-dwarf* HD 140283 and found the abundances of the heavy elements 200 times less in this star than in the Sun (the *relative* abundances of these elements do not differ from the solar values). Oke and Bonsack (1960) investigated the absolute energy distribution in the spectrum of RR Lyrae which after comparison with de Jager and Neven's model computations yielded effective temperatures of 5900 – 7200° and effective g-values between 80 and 4000 cm/sec^2, yielding a true g-value of 475; $R/R_\odot = 9{\cdot}3 \pm 0{\cdot}7$.

The *white dwarf* Van Maanen 2, investigated by Weidemann, has $T_{\text{eff}} = 5800°$, $\log P_g = 9{\cdot}3$, $\log P_e = 2{\cdot}5$; $\log He/H = 1{\cdot}75$. In the photospheres of these kinds of stars, formation of molecules is important.

Photospheric abundances. Aller's book (1961) on the abundances of the elements is about to be published. In the first section much information can be found on abundances. We also refer again to Hubenet's thesis, where the influence of the photospheric structure on abundance determinations was examined, and was found to be small. Neven (1959) stressed that weak-line theories can hardly be applied or not at all, when criticizing Mugglestone's (1958) determination of nitrogen abundances.

Some deviating abundances. Bonsack (1959) found the abundance ratio Li/V to differ for various K-type stars and to range up to a factor 100, which may be due to differences in the internal circulation of these stars.

Boyarchuk (1959) found that the He/H ratio in the bright component of β Lyrae is about 250 times greater than normal.

C. DE JAGER
President of the Sub-Commission

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29*b*. SOUS-COMMISSION DES ETALONS D'INTENSITE DE RAIES

Président: Dr K. O. Wright, Dominion Astrophysical Observatory, Victoria, B.C., Canada.

Membres: Abt, Butler, Greenstein, Houtgast, Melnikov, Plaskett, Righini, Wrubel.

INTRODUCTION

The most important accomplishment in the field of line intensity standards in stellar spectra during the past three years has been the development of a high-dispersion photo-electric scanner at the coudé focus of the Mount Wilson 100-inch telescope. For many years it has been felt that there should be a direct check on measurements of line intensities obtained by the techniques of photographic spectrophotometry. Even at high dispersion there is often a very large range in density on a photographic plate over the small area covered by a sharp stellar absorption line and numerous errors can be made with little probability of detection. Calibration techniques, while fairly well standardized at several observatories, require frequent checks to make certain that conditions under which the stellar and calibration spectra are photographed are as nearly identical as possible. One of the principal aims of this Sub-Commission has been to arrange that spectra of a few selected stars should be obtained and that equivalent widths and profiles of representative lines should be measured at several observatories for inter-comparison purposes and to serve as first-approximation standards in the hope that at least the observational data, on which studies of stellar atmospheres are based, should be comparable. The 'operational' use of the Mount Wilson high-dispersion scanner is an important addition to stellar spectrophotometry and it is hoped that its success will provide new impetus toward the installation of similar instruments at other observatories.

MOUNT WILSON PHOTO-ELECTRIC SCANNER

The following brief description of the Mount Wilson photo-electric scanner has been abstracted from a report prepared by J. B. Oke and J. L. Greenstein:

'One of the purposes of this instrument is to provide accurate measurements of the equivalent widths of spectral lines. It is used in conjunction with the 114-inch camera. The light is detected by 1P21 photomultiplier tubes. One channel of the instrument monitors about 75 Å of spectrum adjacent to the spectral region being scanned. The second channel is used to scan the spectrum. The grating and photo-electric equipment do not move while the spectrum is being scanned. The ratio of the scan and monitor signals, amplified by independent D. C. amplifiers, is recorded continuously. By proper balancing, seeing effects under favorable conditions can be almost entirely eliminated. The observations were made with the grating

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