36. COMMISSION DE LA SPECTROPHOTOMETRIE

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By publishing at each meeting a report on the progress of astronomical spectrophotometry, our Commission has done in the past work which has been appreciated. Such a report may be expected to be of special usefulness in the present circumstances, after the disruption of normal communications for so many years. For this purpose, an attempt has been made to give a list of the most important publications, as a bibliographical appendix to this report. The titles are quoted in abridged form. My thanks are due to many members of the Commission, who contributed materially to this list and helped me with important information. I apologize for omissions, nearly inevitable in this post-war period. In future some restriction of the field of our activity ought to be considered; spectrophotometry is nowadays so general an astrophysical method, that it is nearly impossible to give a more or less complete survey of its applications to all different fields of our science. This report was finished on January 1, 1948. A few recent publications have been included in the bibliographical list.

A great number of papers on the spectrophotometric observational methods have been published in physical and in technical periodicals. In the *Journ. Opt. Soc. America*, the *Industr. Engineering Chem.* (anal. ed., 1941), and the *Bull. Acad. Sc. U.R.S.S.* 1940, etc., much useful information about these technical measurements may be found.

I. SPECTROGRAPHS

For solar spectrographs an important addition is the monochromator which is introduced before the first slit [I, 1, 2].* This instrument intercepts the particularly dangerous stray light of other wave-lengths. It may be made so selective as to transmit only a few angströms, so that even the ghosts of the neighbouring parts of the spectrum are eliminated. By a proper choice of the lenses, the monochromator at the same time magnifies the solar image and thus helps in studying details near the limb.

The construction of stellar spectrographs has been perfected by the introduction of mirrors instead of lenses: an off-axis parabolic collimator is used, and interchangeable Schmidt cameras of different focal length are available, adapted to the particular object under investigation. Thus the chromatic aberrations are practically eliminated. If lenses are used, stray light due to reflection against the glass surfaces should be avoided by coating all optical parts by an antireflex film, a technique now generally used. This not only increases the speed of the instrument, but is especially important for intensity measurements.

Some stellar spectrographs have been made with a dispersion already of the same order as that of a medium solar spectrograph [I, 3, 4]. The Coudé spectrographs of the McDonald and of the Mount Wilson Observatories yield star spectra in which the individual profiles of all stronger spectral lines may be studied (cf. section XI). Wood's aluminum on glass gratings give a dispersion which in many spectral regions is superior to that of prisms.

Attention is drawn to the enquiry of the Swedish National Committee of Physics, concerning the need of gratings and the possibility of manufacturing them.

In order to increase still more the resolving power, a new method may be found in the use of the Fabry and Perot interferometer. This instrument, formerly used for the investigation of extended sources of light, can be applied also to stellar spectra [I, 5].

* Figures in square brackets refer to entries in the Bibliography on pp. 385–98. The Roman numerals indicate the sections under which they are numbered.

Special instruments have been devised for the investigation of faint nebular spectra: the nebular spectrograph and the image-slicer [I, 6, 7].

By means of special spectrographs, located in the head of rockets, it has been possible to photograph the solar spectrum at altitudes of 135 km. and up to λ2200.

II. MICROPHOTOMETERS

A great variety of types for rapid technical measurements has been devised [II, 1]. The precision required for an astrophysical observatory will generally be higher. Some interesting new principles have been applied and will be briefly described.

Two galvanometer spots at a constant distance of say 20 cm. are recorded simultaneously; this device permits the measurement of densities up to 2 [II, 2]. A small part of the light is used for the formation of another spot which is followed by eye while the record is being made [II, 2].

The coupling of the plate motion with the motion of the recording paper can be obtained without gears or periodic errors by means of various devices [II, 2, 3].

An extremely quick record can be obtained by means of a photoelectric cell and a cathode-ray oscillograph [II, 4].

The reduction of transmission curves to intensity curves is a very lengthy process. By the Amsterdam and by the Victoria astronomers semi-automatic devices have been described, allowing even a correction for the instrumental curve [II, 7]. Two completely automatic instruments were devised at Utrecht and at Michigan, the one adapted more specially to the solar spectrum, the other one to stellar spectra [II, 8, 9]. The further development of such instruments is of vital importance for the systematic application of spectrophotometry on a large scale.

III. PHOTOGRAPHIC PHOTOMETRY

Excellent summaries of numerous recent papers on photographic methods are found in the Kodak Abstracts. Here the astronomical contributions only will be reviewed.

International comparison of standard lamps has proved an excellent method in investigations on gradients and colour temperatures. The gradient difference of the lamps is relatively easy to determine, the gradient itself is more uncertain [III, 2, 3, 4].

Apart from the usual incandescent lamps, other standard sources have been investigated, giving a spectrum of more uniform density in a prismatic spectrograph. The tube of molecular hydrogen has been used in the region λ2500–4000 and even λ4200–5000 [III, 6]. A fluorescent plate, illuminated by a mercury lamp, is suitable between λ4400 and 5500 [III, 7].

Recent experience has again proved that a calibration by rotating sectors is sometimes reliable [III, 8], sometimes not [III, 9], even if the flashes are very rapid. By using a quartz plate between two polaroid films, channelled spectra are obtained in which the intensity distribution is known and which may be used for calibration [III, 11].

The influence of humidity on photographic plates has been studied in detail. It effectuates not only a decrease in sensitivity but modifies also the density curves [III, 12]; in about two hours saturation is reached. In normal astronomical work the effect does not exceed $0^m.03$ [III, 13]. When two successive, equal exposures on the same plate are found to have a different density, this is not due to humidity but to the fogging background light, the influence of pre-fogging being different from that of post-fogging [III, 13].

The effect of graininess prevents the discovery of faint spectral lines; in a well-studied case, it proved impossible to detect such lines by comparing a series of successive microphotometer records of the same plate and noting coincidences [III, 14].

In order to avoid halo formation by the reflection of the plate, it has been recommended to cover the back-side by an antireflex layer [III, 15]. Local sensitivity differences, due to a varying thickness of the emulsion, can be detected after development and corrected for [III, 17]. An increase of 1^m or 2^m in the sensitivity of plates has been obtained by hypersensitizing with mercury vapour, by preference at a humidity around 75% [III, 18, 19].

Some special methods of photographic spectrophotometry have been applied, which in certain cases may be of great use. The measurement of stellar spectral lines with a wide microphotometer slit is found to be practical also when the spectra are unwidened and narrower than the slit length [III, 20]. The ratio of two neighbouring emission lines on a continuous background can be derived in first approximation from unstandardized spectra by assuming a mean value of the gamma [III, 21].

IV. DIRECT SPECTROPHOTOMETRIC MEASUREMENTS

Such techniques, used before for the continuous spectrum of the Sun, are being applied now with improved instrumental means to other problems in order to avoid the photographic intermediary. The profiles of solar lines are recorded by a photocell behind a narrow slit; changes in the atmospheric transmission during the record can only be partly compensated by means of a second photocell, used for control [IV, 1].

The photocell and the multiplier phototube have reached such a considerable sensitivity, that they may be combined with different colour filters and make possible a very precise *comparison* between the energy distribution in stellar spectra, though each individual curve is admittedly rough [IV, 2, 2*a*].

In the infra-red, important results have been obtained at the McDonald and McMath-Hulbert Observatories [IV, 3] with new PbS photocells, sensitive up to 3μ. In the McDonald instrument, the beam of light is intercepted 1080 times a second, and the resulting discontinuous photocurrent is amplified. By means of this apparatus, the energy distribution in the spectra of planets and stars has been investigated; recently the resolution has been considerably increased and a cooling system has been introduced. At McMath, solar lines with an equivalent width of only 0·01 A. are clearly recorded [IV, 6]. Several other types of cells have promising qualities for work in the infra-red and are gradually declassified ([IV, 4], an excellent survey).

The classic thermo-element is less sensitive, but is able to record the radiation far into the infra-red. This stresses the importance of instruments such as the beautiful infrared spectrometer of the Liège Observatory [IV, 7].

A direct colorimeter has been constructed by making use of quartz plates and a rotating polarizer, combined with a multiplier; the alternating current produced is amplified and measured [IV, 5].

V. APPARATUS CURVE

Exact determinations of the apparatus curve have been made for the Potsdam and Arcetri grating spectrographs [V, 1, 2] and for the Oxford prism spectrograph [V, 3]. It is only in the first case that a comparison between different wave-lengths is possible, which showed that the width of the apparatus curve is proportional to λ. For the prism spectrograph, the assumption has been made that the line width is mainly due to inhomogeneity of the prisms and that it has the same value in millimetres through the whole spectrum. More experimental research upon this question is necessary. These apparatus curves were determined by measuring the profiles of krypton, neon, mercury emission lines, or from sodium or oxygen absorption lines [V, 3, 6]. From plates taken with the Mount Wilson solar grating for the Utrecht atlas, the asymmetry in the apparatus curve of this instrument was derived. A similar asymmetry was found in the apparatus curves of other gratings [V, 4].

Different mathematical methods have been devised, giving the relation between the observed profile, the true profile and the apparatus curve [V, 5, 6]; computations may be simplified by special apparatus [V, 7, 8]. In order to correct stellar spectra for the influence of instrumental broadening, the 'contraction method' is very practical, though not quite exact [II, 7; XI, 7, 8].

VI. INTENSITY RECORDS AND CATALOGUES

From Mount Wilson plates a photometric atlas of the solar spectrum has been published by the Utrecht Observatory, giving the intensity profiles between λ3332 and λ8771 [VI, 1]. Similar records have been published for nine representative star spectra, photographed with the Coudé spectrograph of the McDonald Observatory [VI, 2, 3]. Information about the apparatus curve of the *Utrecht Solar Atlas* is found in [V, 4], [V, 6], [VI, 4] and [XII, 4].

Allen's photometric catalogue of solar lines has been complemented by measurements in the region λ8800–11000 [VI, 4*a*] and λ3530–3915 [VI, 5]. The calibration of the Rowland scale has been perfected by several authors [VI, 6, 7, 8].

The total energy absorbed by all the Fraunhofer lines together has been redetermined [VI, 8]. The result (9·1 %) will have to be considerably increased by the new interpretation of the ultra-violet solar spectrum [IX, 5].

Concerning the most convenient unit in which equivalent widths should be expressed, a separate note is inserted at the end of this report.

VII. ATOMIC TRANSITION PROBABILITIES

The important task of publishing a catalogue of *f* values has been assumed by a sub-commission of Commission 14. A provisional list of some directly available data is given in our literature list under section VII; they are intended to complement the tables in Unsöld, *Physik der Sternatmosphären*, pp. 128 and 191. These data have been found partly by quantum mechanical calculation, partly by laboratory measurements, either in absorption or in emission.

Among the collected data, the absorption coefficient of H^- is of particular importance; it was found by Wildt to play a preponderant role in the formation of the continuous spectra of the Sun and of G and F stars. Since then, several astrophysicists devoted their work to the calculation of this absorption, a probably definitive solution being given by Chandrasekhar. It would be interesting, but difficult, to make laboratory measurements.

Transitions between excited states were up to now only found by experiment. Goldberg, Aller and their collaborators are trying to find these probabilities from theory.

It would also be important to collect data about the probability of excitation by electron collision as a function of the electron velocity for as many lines as possible. These data are important for comparing the influence of collision and radiation in the formation of Fraunhofer lines; moreover, they are required for the theory of the corona and the gaseous nebulae.

VIII. MODEL ATMOSPHERES. TRANSFER OF RADIATION

The origin of the opacity of stellar atmospheres can now be considered as elucidated to a great extent:

–G 0	Continua near series limits of metals. Perhaps O^-.
G 0	H^- predominant; metal continua in the U.V.
G 0 –A 0	H^- and increasing contribution of H.
A 0	H predominant.
A 0^-	H and electron scattering, sometimes He.

The strong continuous absorption in N stars to the violet of λ4300 is perhaps due to an accumulation of molecule bands [XII, 28].

The importance of H^- in the Sun explains the absence of discontinuities in the spectrum, due to metal continua [VIII, 12, 13]. It is confirmed by the energy-wavelength curve [VIII, 7, 8, 10, 11] and, in a less clear way, by the limb darkening [VIII, 9]. Originally, it seemed that an extra absorption in the infra-red was left unexplained [VIII, 8]; this, however, was afterwards shown to be entirely accounted for by the free-free transitions [VIII, 11].

For the Sun and the other stars for which we now have an exact knowledge of the absorption coefficient, it has been necessary to revise our models of the outer layers [VIII, 24, 25, 25*a*; XI, 1*a*]; many considerations on the energy-wavelength distribution and the colour index, the limb darkening, the formation of Fraunhofer lines, the Balmer discontinuity, the conditions in sunspots, can now be established for the first time on a reliable basis.

For the mathematical treatment of the radiation transfer, new and very effective methods have been found especially by Chandrasekhar [VIII, 3], giving high approximations for problems hitherto scarcely tractable and involving absorption, scattering, polarization, line-formation.

The theory of neutron diffusion, applied to the transfer of radiation, has given for the first time a rigorous solution of the problem of temperature distribution in a grey atmosphere; a detailed table of Hopf's function $q(\tau)$ is now available [VIII, 3*a*, 3*b*, 3*c*]. By comparison, it is found that the 'variational' solutions converge much more quickly towards the exact result than other solutions.

For the real, non-grey atmospheres, there is for the moment a lack of precision in the theory of stellar atmospheres. It appears that the '*Rosseland mean*' $\bar{\kappa}$ is not entirely justified. Chandrasekhar, using a 'perturbation' method, finds that one should take the straight mean of κ_ν [VIII, 3]. Other authors find considerably different results: the methods used are semi-empirical [VIII, 3*g*], or iterational [VIII, 3*h*], or variational [VIII, 3*d* and *e*]. A definitive solution is not yet available.

Another difficulty is the unknown contribution of the far ultra-violet radiation to $\bar{\kappa}$ [VIII, 7 and 11]; this is essentially an astrophysical problem, which cannot be avoided by mathematical skill. The Sun is a real test-case which should be solved before reliable and precise results can be expected for the stars. *Deviations from thermodynamic equilibrium* have an influence which depends on the variation of κ_ν along the spectrum. For the Sun, deviations in the ionization will probably not exceed a small percentage [VIII, 14, 15]; deviations in the excitation were generally considered as noticeable only beyond 12 V [X, 18], but recent work on the infra-red spectrum reveals considerable superexcitation for high levels of Fe I [IV, 6]. The *convection* could also produce deviations [VIII, 16, 18, 18*a*]; but even if the stability condition is infringed, there is only a limited fraction of the energy which is conveyed by convection, while radiation is still responsible for the remaining part; the velocity of the currents is much smaller than one would expect [VIII, 17]. From these considerations it seems that the effect of convection on the structure of stellar atmospheres is only small. The *blanketing effect* has been treated in a more exact way and has been found different according to the stellar model, the ratio between scattering and absorption, and the distribution of the lines over the spectrum. In general, the boundary temperature is changed very little by the Fraunhofer lines; but in deeper layers the temperature is gradually increased [VIII, 19, 19*a*].—All these uncertain effects come in when the limb darkening of the Sun is calculated; considering the discrepancies between different observers, it is for the moment very difficult to draw definite conclusions concerning the factors involved [VIII, 19*b*].

For the outer layers of the Sun, the more inductive method therefore seems safer. From the observed limb darkening, the emissivity $J_\nu(\tau)$ is derived as a function of depth, almost without hypothetical assumptions [VIII, 8, 9]. Unfortunately, slight observational errors have a considerable influence on the results as soon as depths beyond $\tau = 1$ or $1{\cdot}5$ are considered. Therefore deeper layers can only be investigated by the deductive method.

In early-type stars, the electron scattering plays such an important role [VIII, 20, 21), that the limb of such stars must emit light polarized for 11 %. This effect has actually been detected in some eclipsing binaries [VIII, 3, 22, 22*a*].

The radiation transfer in stars with extended atmospheres has been studied for the rather general case $\rho \sim r^{-a}$ [VIII, 27].

A very important undertaking is the systematic construction by Strömgren of theoretical stellar atmospheres, corresponding to different values of the composition, surface gravity, temperature, etc. Such models are a very useful starting point for many other investigations and in due time it will become possible to decide which assumption conforms best to the observations. They have been published now for G, F and A stars [VIII, 23, 24, 25]. For the Sun, the model has been recalculated, taking into account the recent results on the absorption of H^- [VIII, 25*a*]. Calculations about model atmospheres for helium stars (B) are also available [VIII, 20, 28, 29].

IX. SPECTROPHOTOMETRY OF CONTINUOUS SPECTRA

The continuous background of the solar spectrum is an important object for exact measurement and comparison with theory. Some new observations have been made in the region λ3000–7000 [IX, 2, 3].

Very important is the new interpretation of the ultra-violet solar spectrum by Arnulf, Chalonge, Déjardin [IX, 3, 5, 6]; by selecting only the very highest maxima in the ultraviolet, they showed that beyond λ4000 only five windows are found where the real background is observed without influence of Fraunhofer lines; a few other points are only slightly weakened; for the rest, accumulations of Fraunhofer lines cover the whole spectrum. The real background has a gradient corresponding to $T=6700°$ near λ4500 and $T=6100°$ near λ3500.

It is now clear, both from theory and from observations, that the energy distribution in stellar spectra does not correspond to that of a black body. Data concerning colour temperatures and gradients have only a limited value. If slight deviations from the black-body curve occur, the colour temperature and the gradient will be abnormally high in some spectral regions and abnormally low in others. This explains the considerable divergency between authors, working in different parts of the spectrum. The observer only measures certain ratios, from which the temperature at any depth has to be deduced by theory.

The best *standard* for stellar spectra is the A0-star. The observations of Greenwich, Michigan and Göttingen in the region λ4500–6500 yield mean gradients of 1·00, 1·07, 1·19 [IX, 7, 8, 10, 11, 12]. Especially the Göttingen observers consider the observed deviations from this mean gradient along the spectrum as real [IX, 8]. In the violet and ultra-violet spectral region, the work of the Paris observers is of special importance [IX, 14]. For the region λ3700–4500 they find a gradient $\phi_1=1{\cdot}00$; beyond the Balmer limit the gradient is found to be $\phi_2=1{\cdot}39$.

For a great number of stars, *relative comparisons* have been made with this standard. The Göttingen observers have moreover intercompared the stars, making numerous combinations. The results agree beautifully; the divergencies are much smaller here than in the measurements of the A0 standard, because in this last case a comparison had to be made with a standardized lamp [IX, 7, 9, 10, 13, 14]. These relative measurements are beautifully supplemented by the photoelectric determinations over the whole region λ3530–10300 [IX, 15, 16]. The deviations from black-body curves are surprisingly small; in the violet and ultra-violet the results have a limited value, because of the accumulation of Fraunhofer lines.

The relation between gradient, colour temperature and colour index has been tabulated by several authors [IX, 17, 18, 19].

A detailed comparison between the theoretical and the observed energy distribution can be made for G0 and for A0 stars. For the Sun, the agreement is very satisfactory, except in the region $\lambda<4000$ [VIII, 11]. For the A0 stars a precise agreement has not yet been reached [VIII, 4, 20*a*], but this is improved if the variation of κ_ν/κ with depth is taken into account [VIII, 4*a*].

The important relation between colour temperature and effective temperature may now be deduced by three methods:

(1) in a semi-empirical way, from observations on Cepheids [IX, 28, 29];
(2) from the scale of effective temperatures (Kuiper);
(3) from the theory of the absorption coefficient [VIII, 11].

The methods (2) and (3) give a satisfactory agreement, with which the results of method

(1) can be more or less reconciled. The relation between T_c, T_e and the brightness temperature may be deduced similarly from the methods (1) and (3).

By spectrophotometric comparison between stars in different directions and at different distances, the law of interstellar absorption has been determined with considerable precision and for six wave-length regions; this is approximately proportional to λ^{-1}, or more precisely to $\lambda^{-0.56}$ within the interval considered. The trapezium stars of Orion show the influence of an absorption of a different kind [IX, 16, 16*a*].

The Balmer discontinuity near λ3660 has been measured for a great number of stars [IX, 14, 20, 21, 22] and has been accounted for by theory [V, 11]. It is interesting to follow its variations during the eclipse of Algol [IX, 23, 24].

Two direct determinations of the surface temperature T_0 have been made: (1) from the colour temperature in the region $\lambda < 3660$, for stars where the continuous Balmer absorption is sufficiently great [IX, 25]; (2) from the colour temperature of the sun at the extreme limb [IX, 26].

Special investigations relate to some individual interesting objects [IX, 16, 27, 28, 29, 30].

X. CURVE OF GROWTH AND QUANTITATIVE SPECTRAL ANALYSIS OF THE SUN

From multiplets and transition arrays, empirical curves of growth have been derived for the Sun by several authors. These curves again yield a value for 'the excitation temperature of the reversing layer' by assuming a Boltzmann distribution between the atomic levels of each element. In this way, temperatures of 4300°–4900° have been found [X, 1, 2, 3, 4, 5]. (For deviations from equilibrium conditions, cf. Section VIII).

A more detailed theoretical analysis of the meaning of this 'excitation temperature' has been made for the weak lines, taking into account the structure of the solar atmosphere as a function of depth. It then becomes apparent, that such a concept has only a formal significance; the temperatures may be expected to vary between 5000° and 7000°, depending on the wave-length and the excitation potentials [X, 7]. This dependence is qualitatively confirmed by the observations [X, 8]; excitation temperatures from weak lines only have not yet been derived.

From the general shape of the curve of growth, a kinetic temperature of 5400° was found [X, 6].

In a similar way it has proved possible to construct beautiful curves of growth from molecular lines [X, 12]. From such curves or from the intensity distribution in a rotation band, 'rotational temperatures' between 4370° and 5630° have been found [X, 9, 10, 11, 12].

The analysis of abundances in the solar atmosphere requires the solution of four distinct problems: the relative proportion of the metals; the proportion H : metals; the proportion H : metalloids; the proportion H : He. For the first problem, a knowledge of transition probabilities is essential; moreover, if strong lines are used, the damping constant must be known, which is often uncertain. For the second problem, our present knowledge about the continuous absorption in the solar atmosphere makes a direct solution possible, provided the necessary knowledge of atomic constants is available as for the first problem; so each single weak line of a metal atom originates by a competition between selective metal absorption and continuous hydrogen absorption, and therefore yields without any further comparison the ratio H : metal. The basis of an analysis along these lines has been laid in a fundamental paper by Strömgren [X, 15].

The third problem can be solved directly by an investigation of the molecular bands. The fourth problem has been solved only for the chromosphere and the prominences or for helium stars; it would be interesting to investigate the influence of the He concentration on different observable properties of the solar atmosphere.

Data about 'the number of atoms above the photosphere' have no precise meaning and should be translated into hydrogen/metal abundances [X, 13, 14].

Altogether, amazingly few results about the composition of the solar gases have been obtained in these years. They are summarized here (abundances are given in number of atoms).

	(15)	(7)	(12)	(16)
H	8000	8000	8000	8000
C	—	—	9·1	—
N	—	—	8·5	—
O	—	—	14	—
Mg	0·3	—	—	0·14
Ca	0·013	—	—	—
Na	0·007	—	—	0·008
K	0·0016	0·0008	—	—

The importance of the new results for C, N, O should be particularly stressed. A recent analysis of the solar atmosphere has been made by Menzel, of which only the results are published; another was made by Unsöld, but the data published are apparently derived partly from other objects [x, 17, 18].* The great hydrogen abundance, now generally accepted, has been confirmed along different lines of evidence [x, 19]. The discovery of this preponderant importance of hydrogen and of the strong continuous absorption of H^- has made the analysis of the solar atmosphere much easier than one could have hoped.

XI. CURVES OF GROWTH. GENERAL SPECTROPHOTOMETRY OF STARS†

The construction of curves of growth has been applied by many authors as a powerful tool for the analysis of stellar atmospheres; a paper such as that of Unsöld on τ Scorpii covers the whole field [xi, 26]. It has been shown that the f-values, given by the ordinary multiplet rules, are definitely less exact than values derived from laboratory intensities or from solar equivalent widths. These are therefore used by preference.

For stars of the later types, the greatest part of the lines is blended. In such cases, the Amsterdam workers [xi, 7, 8, 9] construct a preliminary curve of growth. They now calculate 'the theoretical spectrum': for each component of a blend, the solar intensity is reduced to the expected stellar intensity via the curves of growth; then the components are compounded. This theoretical spectrum is not yet identical with the observed spectrum; by least squares, differential corrections are applied to the temperature, Doppler effect, damping, ionization, etc., till the best possible fit is obtained. These authors contend, that entirely erroneous results are often obtained by following simpler methods.

Several difficulties have been met in the interpretation of stellar curves of growth. Sometimes the lines of one element do not fit the curve determined by another element [xi, 23]; or the Doppler effect from the curve of growth is not consistent with the line profiles [xi, 13, 14]. Apparently the stellar model for which the curve has been calculated does not correspond with the real star. The following complications have been suggested: special kinds of damping, interlocking, deviations from thermal equilibrium and chromospheric effects, turbulence increasing with height or with the E.P., velocity distribution of a non-Maxwellian type, stratification. The special characteristics of the curves of growth should be derived for each of these cases. More direct information can be obtained of course if it is possible to observe individual profiles on spectrograms with a high resolution. Generally speaking, the results of the curves of growth should be compared as much as possible with detailed profiles. The detailed investigation of profiles is also important because it informs us about complicated motions of the stellar gases; this is the case in M super-giants, in W stars and in stars with extended atmospheres generally.

In the literature list, a survey has been given of well-analysed stars roughly in the order of spectral types. Among the stars studied by general spectrophotometry, the

* *Note added in proof.* Very recently a systematic analysis of the solar atmosphere by the same author was published [x, 18].

† Special spectrophotometry of variables, stars with extended atmospheres, etc., has not been included.

super-giants are particularly well represented; some peculiar and metallic line stars have also been examined. Often, great differences are found between the Doppler temperature, the excitation temperature and the ionization temperature.

In the determination of abundances there is often doubt whether the excitation of higher levels corresponds with thermal equilibrium. For such cases, two methods have been used with profit: (1) We assume that *equally strong* lines, originating from two different levels, are formed by the same number of oscillators (good results for α Orionis, 3). (2) We determine the population of an atomic level of high excitation; then we assume that the excitation is the same for such a level and for the neighbouring resonance level of the ion; by combining the laws of Boltzmann and Saha, we compute the population of the ions, which in many cases is practically the total population [XI, 26].

Variable stars often show such profound variations in their spectrum, that from an analysis along the classic lines considerable differences in chemical composition would be found for one and the same star, depending on the phase. This is the case for some long-period variables, showing an alternation between M and S characteristics; and for several groups of spectrum variables or metallic line stars. Such observational evidence shows that differences in chemical composition between stars may not be assumed, unless we have made sure that no other effects are involved: especially gravitational separation of the elements and superexcitation of some atoms should be considered. The abnormally great abundance of helium which is found in some early type super-giants has been attributed to such a superexcitation of high levels [XI, 27; cf. XIII, 18]; however, the abnormal weakness of the hydrogen lines cannot be explained in such a way. Also in other cases real differences in composition can hardly be denied (novae, W stars, carbon and oxygen stars). Especially interesting is the composition of R-type stars, where the investigation of C_2 bands shows that there occurs a group with a ratio $C^{12} : C^{13} = 50$ or more, and another group where this ratio is 3·4 (cf. XII, 55).

XII. LINE PROFILES, THEORY AND OBSERVATIONS

(*a*) DOPPLER EFFECT AND DAMPING

The role of the Doppler effect in the resonance process appears to be more complicated than what has been realized ordinarily [XII, 5]. It would be worth while to consider the influence of this detailed analysis on the line profiles.

The broadening effect of turbulence in the Sun has been found to correspond with a random velocity of 1·5–1·8 km./sec. [XII, 15, 63].

For the computation of theoretical profiles, widened by stellar rotation, one of the most practical methods is that of Unsöld. It has now been possible to extend this also to great rotational velocities [XII, 6]. The inverse problem remains difficult and can only be solved in a satisfactory way, if the profile of the undisturbed line is known by comparison with similar stars [XII, 7, 8].

The theory of damping has been clarified in several respects [XII, 9]. For the collisional broadening, treated up to now along the lines of Lenz and Weisskopf, Lindholm succeeded in calculating in a clean way the influence of individual passing particles at all different distances [XII, 10, 11]. The phase-disturbances, calculated by quantum mechanics, are practically equal to those found from the semi-classical theory, as long as the passage is described as a static process [XII, 12, 12*a*]. A more exact dynamic description, taking also into account a possible rotation of the radiating atom during the passage, gives somewhat different results [XII, 10, 13, 74].

For the statistical broadening, quantum mechanics have mainly confirmed the existing theory.

These two extreme models are to be compounded in the real cases. The central parts of the line are mainly determined by the collisional broadening, the wings by statistical broadening. A complete formula, giving the transition between both limiting cases, has recently been derived [XII, 12]. In stellar atmospheres, the following effects seem preponderant [XII, 9]:

1. Linear Stark effect on Balmer lines and He II: statistical broadening by ions.
2. Quadratic Stark effect on metal lines and on some He lines: collisional broadening by electrons.
3. Special broadening due to the element itself: ineffective.
4. van der Waals forces on metal atoms: collisional broadening (chiefly by H).

The difficult case 2 has been treated in general and has been especially applied to Ca^+ [XII, 14].

The influence of Stark effect has been looked for, comparing the observed damping constant of iron lines in the Sun with the quadratic Stark effect in the laboratory, but the correlation seems poor [XII, 16]. The width of most Fraunhofer lines seems to be due to the collisions of the radiating atoms with the hydrogen atoms, these being so extremely abundant in the solar atmosphere (effect 4) [VIII, 25; X, 15; XI, 1*a*]. A direct demonstration for the preponderant importance of this factor has been given, by comparing the spectrum of the centre to that of the limb: the damping constants are found to be proportional to the gas pressure and not to the electron pressure in the two effective layers [XII, 63]. It is therefore of great interest to investigate theoretically the influence of H collisions on spectral lines of all different kinds.

By comparing the calculated to the observed damping, the effective level may be found where a Fraunhofer line is formed. For Na this is at $\tau = 0{\cdot}08$ [XII, 16*a*].

The theoretical combination of Doppler effect and damping can now be easily computed by means of several new tables of Voigt profiles [XII, 17, 18, 19].

(*b*) Scattering and Thermal Absorption

The relative importance of these two processes, which was discussed so eagerly some ten years ago, remains partly unsolved and has not been closely investigated further in the last period. This is understandable, in so far that both theories give more or less the same values of the equivalent width. From the experimental side, evidence may be obtained by observations concerning the centre-limb variations of the solar spectrum; however, this criterion is less decisive because of the complicating effects of non-coherent scattering. For strong lines, it seems well-established that thermal absorption is ineffective [XII, 65].

A theoretical approach would be relatively easy, if the effective cross-sections of excited atoms for collisions of the second kind were known. This again stresses the importance of such atomic data.

(*c*) Macroscopic Effects

The theory of faint Fraunhofer lines is in many respects of remarkable simplicity. In this case it is possible to take fully into account the detailed structure of the solar atmosphere and the changes of temperature and pressure with increasing depth. The integrations have been carried out once for all and the results are available in a practical form [X, 7]. This is a good standard case for studying the influence of the stellar model, of wave-length and of excitation potential. Here it becomes very clear that the concept of 'effective layer' is misleading and may be better left out.

For strong lines, the method which was used for faint lines may be applied to the wings. For other parts of such lines, the problem of radiation transfer may be treated only by numerical integration of the differential equations or by simplifying the model. So it has been recently solved analytically for a new special case: $1/1+\eta = a + b\tau + c\tau^2$ [XII, 20]. Combination of this case with $\eta = \text{const.}$ gives useful new possibilities [XII, 29]. Apart from such special cases the general macroscopic theory of line formation in model atmospheres has been refined by application of the new analytical methods of Chandrasekhar [XII, 66, 66*a*]. The inverse problem has been treated theoretically by Plaskett

https://doi.org/10.1017/S0251107X00014048 Published online by Cambridge University Press

[XII, 22] and applied by him to the Mg line λ5184. From the observed profiles at different points of the solar disk, it is possible to derive the variation of the line absorption with depth, and subsequently the temperatures and pressures at different depths. The solution thus obtained is unique [XII, 23]; it was obtained first by numerical trials, later by direct analysis [XII, 24]. These methods will have their full use, when the brightness at the extreme limb of the Sun can be determined. It is interesting that a similar method has been applied to the same Fraunhofer line λ5184 by Parchomenko, but the results are neither easily comparable nor complete [XII, 25].

The formation of absorption lines in a moving atmosphere gives considerable mathematical difficulties, due to the relative Doppler effects involved [XII, 25*a*]. For the case of a uniformly expanding atmosphere of the Schuster-Schwarzschild type (super-giant star), the lines are found to be displaced towards the violet, but to develop an asymmetric wing towards the red. For a differentially expanding atmosphere, the problem is much more complicated.

A general continuous absorption or a broad wing, superposed upon a spectral line, is known to weaken this line. Several new instances of this effect have been discovered, which in general are well explained by theory [XII, 26, 27, 28, 28*a*].

(*d*) Hydrogen Lines

Some new observations have been made about the profiles at different points of the solar disk [XII, 29, 30] or about the equivalent widths in stars [XII, 31, 32, 33, 34, 35, 51]. The well-known difficulty of drawing the continuous background for H_α has been solved by Evans [XII, 29] by photographing on the plate the continuous spectrum of a ribbon lamp (the run of the background being mainly determined by the change of plate sensitivity with wave-length); this practical method could be easily refined, taking into account the temperature difference lamp: Sun. A comparison of the results with the classical theory of Pannekoek and Verwey shows again that a general qualitative, but not a quantitative agreement has been reached. It should be noted that the original theory has been revived with an improved coefficient of continuous absorption and with improved values of the weights of the components. The effect of uncompensated cycles seems negligible [XII, 29]. The most probable hypothesis is a superexcitation of the high atomic levels in surface layers ($\tau < 1$) [XII, 30]. Very interesting are the numerous hydrogen lines of high levels in the infra-red solar spectrum between 7 and 14μ [VI, 6].

Equivalent widths have been theoretically computed [XII, 35] in order to compare them to Redman's observations on eclipsing binary stars. Here also there is some agreement, though rather poor.

Several authors have tried to derive the electron pressure in a stellar atmosphere from the number of higher Balmer lines, visible as separate emissions [XII, 36, 37, 38]. Pannekoek's theory of this phenomenon [XII, 36], especially pp. 705–9, ascribes the main effect to statistical broadening; this has been confirmed since [XII, 38], while the observations seem to agree beautifully with the calculations [XII, 39].

(*e*) Special Lines

The helium lines have been first investigated in early stars, without a detailed discussion of the broadening effects [XII, 40]. It was shown that the apparently anomalous weakening of the singlet lines, as compared with the triplet lines, on either side of spectral class B4 results from the properties of the curve of growth and does not require departures from equilibrium conditions. Afterwards the mechanism of broadening was discussed, which for many helium lines is the quadratic Stark effect of colliding electrons [XII, 36]. Especially interesting is the complicated broadening of λ4471 and 4062, investigated by three authors independently [XII, 41, 42, 43, 44]; Struve's interpretation is confirmed.

Measurements of the sodium lines have been made by several authors [XII, 45, 46, 48, 49].

An excellent discussion has been given of the central intensity, taking into account fluorescence by cycles involving free electrons [XII, 47].

The Mg line $\lambda 5183$ in K stars is very sensitive to surface gravity, but its behaviour is difficult to explain theoretically [XII, 49, 49*a*]. Calculations taking into account the new conceptions about H concentration and H^- have not yet been made.

Very interesting is the reversal in the core of the Ca^+ line K in red super-giants [XII, 52, 53; XI, 3], analogous to similar details in the solar K line. This is explained by temperature inversion in the facular regions.

Bands of CN and CH in late-type stars seem to conform well with theory [XII, 56].

(*f*) Spectrophotometry of Small Dispersion Spectra

The spectrophotometric investigation of small dispersion spectra especially for statistical purposes has been further developed chiefly at the Yerkes, Stockholm, Uppsala and Cleveland Observatories. This is now done mainly by visual inspection at Yerkes [XII, 57], from intensity drawings at Cleveland [XII, 58], from microphotometer records at Stockholm and Uppsala [XII, 59, 60].

(*g*) Centre-limb Variation of Line Profiles

Observations about these phenomena are the only way of ascertaining how Fraunhofer lines are formed and of obtaining information on the conditions in deeper layers of the Sun. While the profiles or equivalent widths are ordinarily measured for the centre of the disk and for 'the limb' only [XII, 45, 46, 61, 62, 63], it has been found now that they actually are changing in a systematic way all along the radius. The important investigation of these changes has been carried out for the strong Fraunhofer lines [XII, 64, 65]. The explanation of the observations is still incomplete. The following assumptions have been tried:

1. Owing to the roughness of the solar surface, even near the limb we are not really looking under grazing incidence; $\cos\vartheta = 0{\cdot}05$ corresponds effectively to $\cos\vartheta = 0{\cdot}20$ [XII, 61].

2. Reduced re-emission, due to interlocking. It has been proved that this in any case is not the whole of the effect [XII, 62].

3. Anomalous temperature distribution in the outer layers [XII, 62].

4. The methods of computation should be refined, better values for $\bar{\kappa}$ should be used [XII, 66].

5. By the scattering process, the frequency of the emitted line could be different from the frequency of the absorbed line. This process is predicted by quantum theory when both levels have a natural width ('Weisskopf doublet'). It seems probable that the same occurs, but to an increased amount, when the levels are also broadened by collisions [XII, 65].

6. Owing to collisions, an electron, reaching a sublevel of the higher level, could be 'redistributed' over the whole of these sublevels, independently of the absorption frequency. In this case, there is no correlation between an individual absorption process and the subsequent emission [XII, 65].

The assumptions 5 and 6 should be carefully distinguished. Eddington's 'redistribution of frequencies' is essentially different from 'redistribution of the electron' over the sublevels. In both cases radiation is transported from the wings to the core of the Fraunhofer line, but this effect is stronger for hypothesis 6 than for 5. In the assumption 5, there is phase coherence between the radiation absorbed and the radiation emitted; hypothesis 6 only should be called 'non-coherent scattering'. It seems probable that quantum theory accounts for one or for both of these assumptions [XII, 74]. Hypothesis 5 has never been carefully tested; hypothesis 6 was found to account for most of the observations [XII, 65, 72]. The equation of transfer for this last case has been derived and discussed by several authors [XII, 65, 71, 72]. It is not sure whether, from purely observational reasons, hypothesis 6 is to be considered as necessary; it may be that some of the other assumptions proposed give also satisfactory results. Quantum theory should decide which processes are *a priori* excluded, possible or necessary [XII, 72, 74].

Closely related to these investigations is the search for polarization in Fraunhofer lines near the limb. That this effect has not been found [XII, 67, 68] has been explained by the collisions [XII, 69, 70, 73]. This is strong evidence in favour of the assumptions either 5 or 6.

(*h*) COMPOSITE SPECTRA

In double-star investigation, the determination of the magnitude difference between the components is of great importance. For about 10% of the binaries, the luminosities of the components are of the same order and the lines of the two components are seen periodically superposed or separated; in other cases the luminosities are more different, and the effect of the fainter star is only shown by a distortion of the profiles. A spectrophotometric analysis of the composite spectrum is now made, (*a*) when the lines coincide, (*b*) when they are displaced over a distance Δ. If the assumption is made that the lines have the same profile in both components, the luminosity ratio can be computed in a simple way; the dimensions, orbits and masses of the separate components are found; the mass-luminosity relation can be tested [XII, 75–82].

It is clear that the hypothesis of equal profiles in the component spectra should be improved. Working more carefully it has been possible to find both the spectral class difference and the brightness ratio [XII, 76]. These methods are now in regular use at the Victoria Observatory [XII, 77, 78]. They have proved of special importance for the detection of A or B sub-dwarfs [XII, 81].

XIII. SPECTROPHOTOMETRY OF SPOTS, FLARES, CHROMOSPHERE, PROMINENCES

From former researches it was known, that the temperature of *spots*, derived from the continuous spectrum, is found to be lower when the spots are larger. This has been confirmed for an exceptionally big spot of November 1938, where the record minimum of 3690° was found [XIII, 1], cf. also [XIII, 11]. An almost equally low excitation temperature of 3800° has been derived from the spectrum of other big spots [XIII, 2]. The curve of growth in spots, compared with that of the photosphere, is modified by: (1) the lower temperature; (2) the Zeeman effect, which may be treated more or less as a Doppler effect; (3) the different 'number of atoms' NH.

This ratio $\frac{\text{NH (spot)}}{\text{NH (phot)}}$ is found to be 9·1. The true width of the lines in the spot spectrum is nearly twice that of the photospheric lines [XIII, 2]. The profiles of the Mg *b* lines in the spot have been determined. A theory of the spot should provide the explanation of several of these spectrophotometric results; such a theory has been developed [XIII, 4, 5], but it has to be corrected, taking into account the overwhelming hydrogen content of the Sun and the importance of H^- absorption.

The first careful spectrophotometric analysis of the *faculae* has been carried out and has yielded information about temperature, electron pressure and ionization in these objects [XIII, 4*b*].

Spectrophotometric work has deeply modified our conception of *the chromosphere*. In 1938, we believed that the turbulent state of these layers was demonstrated by threefold evidence: (1) the direct picture of the very irregular spikes and jets; (2) the widths of the chromospheric lines, exceeding by far the normal thermal widths and independent of the element considered; (3) the decrease of chromospheric density as a function of height which was considered to be independent of the element (cf. Unsöld, *Physik der Sternatmosphären*, ch. 98). Since then, this beautiful agreement has been disturbed in a most surprising way: (1) The apparently turbulent motions became still more convincing by the films of Lyot and of the McMath Observatory. (2) However, the line profiles, measured by Redman [XIII, 6] with great instrumental skill, proved to be narrower than expected, and to be markedly different according to whether H, He or metal lines were investigated; if these widths are considered as real thermal widths, a consistent temperature of 30,000° is found. (3) The gradients, derived by Wildt [XIII, 7] from a more extensive material and using recent information, were found different according to the elements, at least in the lower layers; they correspond with temperatures of 30,000°–100,000°. The contradiction between the first qualitative evidence and the other quantitative arguments is very striking, and will probably be explained only when the hydrodynamics of the chromosphere are better understood.

In the investigations just described, kinetic temperatures are derived from line widths and from the barometric gradient which amount to 30,000°. For the excitation temperatures, derived from the comparison of lines of different ionization potential, temperatures of the order of 5000° are found. From the comparison between singlet and triplet lines of He, similar temperatures of 4300°–6700° have been determined, which are essentially also excitation temperatures [XIII, 8].

The *solar flares*, which have proved so important for the investigation of solar and terrestrial relationships, are still imperfectly understood. Spectrophotometric research has been made first with very rough methods [XIII, 9, 10, 13, 14], later more precision has been reached [XIII, 11, 12]. The flare spectrum resembles an ordinary Fraunhofer spectrum of a temperature raised by about 100°, and upon which an emission spectrum is superposed. Compared with the flash spectrum, all Fe^+ lines and all low-excitation potential Fe lines are enhanced (in metallic prominences or hot chromospheric spots, only the Fe^+ enhancement is observed).

It is apparent that a clear distinction between bright flocculi and solar flares has not always been made; it seems that flares have a brightness at least equal to 2·8 times that of the chromospheric $H_{\alpha 2}$ [XIII, 11]. At the limb, most eruptions have between 0·4 and 1·4 times the brightness of the continuous spectrum [XIII, 12]. In flares called 1, 2, 3 on the international scale, the central intensity of H_α is of the order of 0·6, 1, 2 [XIII, 13, 14]. From estimates of the very slightly increased brightness of the continuous spectrum, the density in a flare is found to be 300 times the density in prominences [XIII, 13]. Much work remains to be done in this field; it will be especially necessary to take into account the slit-width and to distinguish between line-width, central intensity, total intensity, brightness area, etc.

Bright and dark flocculi have been compared to the adjacent areas in H_α-light; the Arcetri observers find somewhat higher results than the Greenwich measurements [XIII, 11]. Also bright K_3 flocculi have been examined [XIII, 15].

The older work of Minnaert and Slob on the spectrophotometry of *prominences* has been repeated with great care at Cambridge [XIII, 16, 17]. The results concerning the ration H_α : He have been mainly confirmed; the explanation by self-absorption in H_α seems to be correct, and the curve of growth is found to correspond to 5000°. In part of a prominence, however, this ratio was found to decrease with height (after correction for self absorption), apparently because of the increasing H ionization. Spectrophotometry of an eruptive prominence showed surprisingly small differences with ordinary prominences. The excitation and ionization are normal up to 10 V. and correspond to $T=5000°$; for higher excitation potential the temperature increases, it corresponds to 20,000° between 20 V. and 54 V. [XIII, 18].

After strong solar flare, a search has been made for the Ca^+ absorption spectrum in the gaseous cloud ejected by the Sun. There is indeed an indication that the H and K lines are slightly enhanced at such moments, the additional absorption being displaced towards the ultra-violet by the Doppler effect. But the evidence is not yet conclusive [XIII, 20, 21].

XIV. ATMOSPHERIC LINES

The theory of atmospheric O_2 lines is much simpler than that of Fraunhofer lines, in so far that light absorbed or scattered can be considered as lost. The complications arise because of the decrease of T and P in the atmosphere at greater heights. These effects now have been accounted for very carefully [XIV, 1, 2]. Great discrepancies are found between the observations of different authors, probably because the continuous background has been drawn erroneously. Taking this into account, it may be said that the calculated intensities agree sufficiently with the observed values. Atmospheric temperatures may be determined rather precisely from the spectrograms. Theory predicts also variations in wave-length; O_2-lines should not be used as standards without some precautions.

From the emission of the Earth and of the Moon, compared in the region of the infra-red ozone band, reliable values have been obtained for the stratosphere temperature [XIV, 3].

The intensity of atmospheric vapour lines has long been used as a measure for the amount of water vapour in the atmosphere. Such determinations could be made in a more reliable way with modern insight. Trials in this direction have been made [XIV, 4, 5].

Many other investigations on the infra-red solar spectrum reveal telluric lines, but as yet the results seem to be more spectroscopic than spectrophotometric [XIV, 6].

XV. COMETS

The understanding of physical phenomena in cometary gases has considerably progressed, and a detailed explanation of several spectrophotometric phenomena has been reached.

Assuming that the cometary bands are produced by resonance, Swings pointed out that the accidental grouping of Fraunhofer lines in the exciting solar spectrum would lead to an irregular intensity distribution among the rotational lines of the comet [XV, 6]. McKellar was able to confirm this theory from the CH, CH^+, CN and other bands, to account in detail for the intensities of the rotation lines, and to detect the influence of the Doppler effect when the comet approaches or leaves the Sun, the Fraunhofer lines being shifted with respect to the comet lines [XV, 7, 8, 9, 10, 11]. Most kinds of molecules are found to exist in the lowest rotational levels. At smaller distances to the Sun, the rotational temperature of the molecules increases. For comet 1940c the rotational temperature from CN was 300° at 0·92 A.U., 435° at 0·54 A.U.; for comet 1942g at 1·38 A.U. the temperature was 200°. The temperature derived from CH was found to be 200° at 0·54 A.U. Only the homonuclear molecules $C^{12}C^{12}$, which do not emit dipole radiation in the infra-red, reach much higher rotational distributions, corresponding to temperatures of 2000–3000°. The difference between the $C^{12}C^{13}$ and the $C^{12}C^{12}$ bands is especially striking in this respect.

That the intensity distribution over the rotational lines varies with the distance of the comet to the Sun had long been observed in the bands of CH and CN; it was also known that the intensity maximum is in general shifted towards higher rotational quanta [XV, 3].

This effect is now analysed into two influences, which should be carefully distinguished: the apparently irregular shift is due to the Doppler effect, as explained above; the systematic increase in excitation is due to the increasing rotational temperature. This last phenomenon is attributed by Wurm to the effect of the greater radiation density on the number of emissions and absorptions [XV, 1, 12]. Alternative explanations seem now less probable [XV, 2, 4, 5].

Similar effects have been found for the distribution of the molecules over the vibrational levels: here also we find the influence of the distance to the Sun and the difference between homo- and heteronuclear molecules.

Our knowledge about abundances in comets is still very imperfect, especially because oscillator strengths are uncertain or unknown. There is no real evidence for differences in composition between different comets.

XVI. CORONA

Since the emission lines of the corona have been identified, photometric measurements on these lines take an increased significance. Progress in this field of observations has been slow, perhaps because of the variability of intensities and intensity ratios. The best intensity measurements are collected in [XVI, 1], to which some new results should be added [XVI, 2]. It should be recommended that equivalent widths be reduced to absolute values, if possible, and expressed in angströms of the adjacent continuum or in millionths of an angström of the photospheric spectrum [XVI, 3, 6, 7].

The radial intensity gradient of $\lambda 5303$ proves to be much steeper than for the continuous light. The profile has been measured by several authors and is described as a gaussian curve, corresponding near the limb to a mean velocity in the line of sight of 37 km./sec.; at a height of 3′ 38″ this has decreased to 19 km./sec. [XVI, 4, 5, 6, 7, 8, 9]. These widths have been attributed first to turbulence, but are now mostly considered as due to very high temperatures. In some bright patches, the line is broader and shows a central reversal [XVI, 5].

From the comparison between the intensities of several lines, an excitation temperature of $2 \cdot 10^6$ till $3 \cdot 10^6$ has been derived. From the absolute values of the intensities, the abundances of the several elements were determined. The number of electrons is found to be 10^7–10^8 times the number of these ions; since the corona must be electrically neutral, an enormous number of protons, invisible to us, has to be assumed [XVI, 10].

The importance of absolute data became clear when it was tried to explain the corona lines by emission of meteoric matter. It seems that the number of meteors of different sizes, as ordinarily assumed, is sufficient to explain the intensities observed. The kinetic energy of the falling particles is of the right order for an explanation of the high coronal temperatures [XVI, 11].

New careful spectrophotometric measurements of the Fraunhofer lines in the outer corona and of the polarization have furnished the data necessary for an analysis of the coronal radiation into two components: component I, scattered by the electrons around the Sun; and component II, scattered by the dust particles in the interplanetary space at great distances from the Sun. Component I is responsible for the polarization, component II for the Fraunhofer lines. The problems concerning the corona have been much clarified by this new insight [XVI, 13, 14, 15].

From the work of Grotrian, it was taken for granted that the corona shows the H and K lines as broad depressions, widened by the Doppler effect of the electrons. Menzel however did not observe these depressions at all. Doplicher finds them, but his records fail to show any broadening, the lines have exactly the same profile as in the solar spectrum [XVI, 16]. This interesting question should be elucidated.

XVII. INTERSTELLAR LINES

Total absorptions of interstellar lines, formerly often determined by estimation, are now generally measured by means of the microphotometer; there is no doubt that the accuracy has been greatly improved by this technique. The total absorptions of K, H, D_1, D_2 have been measured for a number of stars [XVII, 1, 2, 3]. They have been generally used as an excellent measure for distance, to which they seem to be proportional [XVII, 4*a*]. Unexpected difficulties were met [XVII, 5] in the interpretation of the line intensities, probably due to our lack of knowledge about the state of motion of the interstellar gas. These intensities could only be explained by assuming that the turbulent velocity of the Ca^+ atoms is about three times that of the Na atoms which seems hardly admissible. As long as this essential difficulty is not solved, the derivation of abundances in the interstellar gas becomes uncertain.

The discovery of complex interstellar H and K lines as of common occurrence is extremely important for our model of the interstellar medium; it looks probable that it will give also the clue to the understanding of the intensity ratios [XVII, 5, 6]. From the number and the intensities of the components, statistical data are found concerning the size and the number of gaseous interstellar clouds [XVII, 7].

XVIII. NEBULAE

Spectrophotometric observations concerning the Orion nebula have been made by several authors [XVIII, 1, 2, 3, 4]. About the continuous background, the Balmer discontinuity, the colour of the nebula compared with the stars, etc., there has been considerable disagreement, which is probably explained now by the lack of resolution of some of the spectra used. The continuous spectrum is interpreted as a capture spectrum, to which some light diffused by the free electrons has been added. From this continuous spectrum an electron temperature of 28,000° or more is found, which looks abnormally high. Lines of high excitation are concentrated near the centre of the nebula, and in general the intensity of the lines is closely correlated with the intensity of the continuum.

From a comparison between the line width, determined with the interferometer, and the local wave-length differences, it is possible to estimate the size of the turbulent units composing the nebula [XVIII, 4].

Important observational and theoretical research has been done on planetary nebulae [XVIII, 5, 6, 7, 8, 9, 10]. The electron temperatures were found from the nebulium lines and from the Balmer continuum to be 6000–10,000°; from the continuous spectrum, a density of 10^4 electrons/cm.^{3} was derived. The origin of the visual continuous spectrum is uncertain. The derivation of abundances is still difficult, since discrepancies of a factor 50 may occur between different authors [XVIII, 10].

Two important papers on the Crab nebula give information about the very special character of this object [XVIII, 11, 12, 13]. The Balmer discontinuity is faint or absent, the colour temperature very low (6000–8000°); the hydrogen content must be very small. Here also, many divergencies between the authors are left open for discussion, as well about the observations as about the interpretation. Oort's recent explanation of the luminosity of this nebula should probably change the whole model.

Theoretical research on the population of the atomic levels and on the electron velocity distribution in nebulae is also of importance for the theory of stars with extended atmospheres. In several cases it has been possible to establish formulae, giving a continuous transition between both cases. It has been proved that in planetary nebulae the velocity distribution is Maxwellian [XVIII, 14, 15].

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REPORT OF THE SUB-COMMISSION ON THE UNIT FOR TOTAL ABSORPTION

At the Meeting of the I.A.U. at Stockholm, the following resolution was proposed by Dr Dunham to the Commission on Spectrophotometry:*

The Commission suggests that, in measurements of total absorption of stellar lines, a unit be used, defined as the light contained in a stretch of the continuous spectrum having a width equal to one-millionth of the wave-length of the line. This unit will be called the Fraunhofer, and will be abbreviated F.

After a short discussion, it was decided that the President of the Commission should nominate a sub-commission, in order to study the question and try to formulate a preliminary advice before the next Meeting.

The following scientists were so kind as to accept the membership of this sub-commission: MM. Dunham, Eddington, Menzel, Minnaert, Pannekoek, H. H. Plaskett, Russell, Struve, Unsöld.

In the spring of 1941, a preliminary note was sent to the members by the President. Seven of them replied that they were in favour of the resolution and gave several additional arguments. Two members had no objection, but asked to postpone the decision till the war was over in order to avoid confusion in the notations and units. Shortly afterwards the international connections were completely disrupted.

* *Trans. I.A.U.* **6**, 418, 1938.

The spectrophotometric work done since 1941 has not changed in any important respect the considerations which seemed valid then. We may assume that the majority of the sub-commission recommends the adoption of the resolution; full consideration is given to the wishes of the minority, since the resolution will be discussed at Zürich by the whole of Commission 36, after a long preparation.

The original note to the members, complemented in several respects by the answers received, is reproduced below.

Preliminary Note

Symbols used:

$\mathfrak{N}$ = number of effective atoms or ions 'above the photosphere' $\times f$;
i_0 = intensity in a point of the continuous spectrum near the line considered;
i = intensity in a point of the profile;
ν = frequency $= c/\lambda$;
γ = damping constant. For classical radiation damping: $\gamma = \gamma_0 \nu^2$;
k = selective absorption coefficient;
c = velocity of light;
v = velocity of the Doppler motion $= \sqrt{(v^2_{\text{therm}} + v^2_{\text{turb}})}$;
$\Delta\nu_D$ = frequency shift of a line by the Doppler motion;
μ = molecular weight;
const. = any constant, independent of the quantities mentioned in the formula, but different from one formula to another.

The equivalent width (= total absorption) of a Fraunhofer line is ordinarily expressed by: $\Delta\lambda$, $\Delta\nu$, or $\Delta\omega$, while Dr Dunham* proposes $\Delta\lambda/\lambda$. The relations between these symbols are:

$$\Delta\lambda = c/\nu^2\,\Delta\nu, \qquad \Delta\omega = 2\pi\Delta\nu,$$
$$\Delta\nu = c/\lambda^2\,\Delta\lambda, \qquad \Delta\lambda/\lambda = \Delta\nu/\nu.$$

In a private conversation, Dr A. S. Eddington proposed the use of $\Delta\lambda/v\lambda = \Delta\nu/v\nu$.

We shall first give a short survey of formulae for the equivalent widths of Fraunhofer lines, broadened by Doppler effect and damping.

1. Faint Lines

$$\Delta\lambda = \text{const. } \mathfrak{N}\lambda^2,$$
$$\Delta\nu = \text{const. } \mathfrak{N},$$
$$\Delta\lambda/\lambda = \Delta\nu/\nu = \text{const. } \mathfrak{N}/\nu = \text{const. } \mathfrak{N}\lambda.$$

2. Strong Lines (broadened mainly by damping)

$$\Delta\lambda = \text{const. } \lambda^2\sqrt{(\mathfrak{N}\gamma)},$$
$$\Delta\nu = \text{const. } \sqrt{(\mathfrak{N}\gamma)},$$
$$\Delta\lambda/\lambda = \Delta\nu/\nu = \text{const. } \sqrt{(\mathfrak{N}/\nu \,.\, \gamma/\nu)} = \text{const. } \sqrt{(\mathfrak{N}\lambda \,.\, \gamma\lambda)}.$$

For classical radiation damping:

$$\gamma = \gamma_0\nu^2 = \gamma_0/\lambda^2, \text{ and } \Delta\lambda/\lambda = \Delta\nu/\nu = \text{const. } \sqrt{(\mathfrak{N}/\nu \,.\, \gamma/\nu)} = \text{const. } \sqrt{(\mathfrak{N}\gamma_0)}.$$

* The same had already been suggested by D. H. Menzel, *Ap. J.* **84**, 465, 1936.

3. All Lines

Construction of Theoretical Curves of Growth

From the general formula of the equivalent width, it is easily seen that for the construction of theoretical curves of growth the number of variables may be reduced by a judicious choice of the co-ordinates.* It is therefore customary to plot:

$$\log \Delta\nu/\Delta\nu_D \text{ against } \log \mathfrak{N}/\Delta\nu_D, \text{ with the parameter } \gamma/\Delta\nu_D.$$

This is equivalent to

$$\log \Delta\nu/\nu v \text{ against } \log \mathfrak{N}/\nu v, \text{ parameter } \gamma/\nu v \text{ (classical damping } \gamma_0\nu/v)$$

or $$\log \Delta\lambda/\lambda v \text{ against } \log \mathfrak{N}\lambda/v, \text{ parameter } \gamma\lambda/v \text{ (classical damping } \gamma_0/\lambda v).$$

The curves thus obtained are valid for all wave-lengths and multiplets and could be called: 'reduced curves of growth'. These constitute *a uni-parametric family*, which is a great advantage and simplification for the computations.

However, it must be remembered that the parameter has another value in each wave-length region. When λ varies, a curve of growth with a given damping factor γ is inevitably modified and changes into another curve of the family. Only if γ should be proportional to ν, would the curve be independent of λ.

Construction of Curves of Growth from Stellar Spectra

In this case, we ordinarily assume that the damping factor γ has a certain mean value, because too little is known about its variations for the individual lines. Apart from this the most exact way of plotting these curves would be to use the same co-ordinates as for theoretical work. The suggestion of Dr Eddington is to adopt for the equivalent width the unit $\Delta\lambda/\lambda v$, which is directly suited to this graphical construction.

However, in many cases the temperature of the reversing layer is not well known *a priori*. It would, therefore, seem advisable to choose $\sqrt{(\mu)}\,\Delta\lambda/\lambda$ in order to eliminate the differences between the atoms. But then the difficulty appears, that there is also a part of the Doppler effect due to turbulence, which is independent of the atomic weight.

The proposition of Dr Dunham is to use $10^6 . \Delta\lambda/\lambda$.† This is less far reaching and leaves it to every author to decide whether he will simply plot the values of $\Delta\lambda/\lambda$ which the observer has tabulated, and derive afterwards a mean value for v; or whether he will take into account the more uncertain difference between the Doppler effects of the several atoms.

The use of such 'reduced' curves of growth is of special advantage for the study of stellar spectra, where only a few lines are free from blends. Multiplets of all different parts of the spectrum are then used together in order to determine the curve of growth. Values of $\mathfrak{N}$ may be compared directly in any spectral region. By sliding the curve in the horizontal and vertical directions till it coincides with one of the theoretical curves, the absolute values of $\mathfrak{N}$ and v are determined. The influence of R_c, the central depth for strong lines, can be taken into account afterwards as a constant factor affecting ultimately v (Unsöld). The curve giving the best agreement determines the parameter $\gamma\lambda/v$ and thus γ.

By plotting as ordinates $\Delta\lambda/\lambda$, we must not hope that our curves of growth for different wave-length regions will coincide. We may slide them in a horizontal direction till the faint lines coincide, the important horizontal shoulder having more or less the same shape. But then in the region of the strong lines the curves for different wave-lengths will not check (factor $\sqrt{\lambda}$ in the ordinates); this is not too important, because there the points scatter anyway, due to the individual variations of the damping factor.

* Cf. van der Held, *Zs. f. Phys.* **70**, 508, 1931; Minnaert and Slob, *Proc. Acad. Amsterdam*, **34**, 542, 1931; Mitchell and Zemansky, *Resonance Radiation and Excited Atoms* (Cambridge, 1934); Unsöld, *Physik der Sternatmosphären*, pp. 168, 266, etc.

† This has already been done by Allen, *Mem. Commonwealth Solar Obs.* **5**, 21, 1934.

For the use of reduced curves of growth, the following restrictions should be made.

1. The determination of $\mathfrak{N}$ for a spectral line does not give directly the number of 'effective atoms above the photosphere'; a quantum-mechanical calculation or an experimental measurement of f is first required. It is not allowed to connect separate wave-length regions by multiplets or supermultiplets with distant members. A direct comparison between the concentration of the effective atoms is still less possible, because the 'height' of the photosphere varies with the wave-length.

2. The curves of growth have a slightly different form, according to the distribution of the effective atoms over the depth (ionization, excitation); the law $i/i_0 = F(k)$ is, strictly speaking, different for each spectral line.

3. If the damping were the classical radiation damping, it would vary proportionally to ν^2. The quantum-mechanical radiation damping should be roughly proportional to ν^3.* However, damping by collisions with H atoms seems to be the preponderant effect; this varies from line to line, and disturbs the exact run of the curves of growth.

4. The formulae used give a central intensity zero. Several more refined theories have been proposed, taking into account cyclical transitions, interlocking, etc. Unsöld has developed a semi-empirical formula, from which it is seen that the equivalent widths derived for a central intensity zero may be in error by 20% for strong lines, and by much more for lines of medium intensity.†

5. The formulae cannot be applied to H and He^+ lines, where the statistical broadening is preponderant.

Other Advantages of the New Unit

The introduction of the unit $\Delta\lambda/\lambda$ has also the following important advantages:

(*a*) It is a pure number. This advantage would not be reached if we adopted $\Delta\lambda/\lambda . c$ in km./sec. (Beals, Merrill).

(*b*) No constant factors are involved.

(*c*) 1 F corresponds to about 0·005 A. in the central part of the spectrum. This means that for most lines the new unit is adapted rather nicely to the present accuracy of the spectrophotometric measurements.

(*d*) $\Delta\lambda/\lambda = \Delta\nu/\nu$. This symmetry is useful in many cases. When $\Delta\lambda$ or $\Delta\nu$ were used, there was always some hesitation which of them should be preferred.

If it could be expected that more exact methods would soon be found for the investigation of star-spectra, it would be advisable to defer any decision about the units to be used. However, for the moment the construction of curves of growth in the simple way now used is practically the only systematical method of analysis, and a vast amount of work has still to be done on that basis; as long as this is the case, the unit $\Delta\lambda/\lambda$ for the measurement of equivalent widths seems very useful.

M. Minnaert
President of the Sub-Commission

* Menzel, loc. cit. p. 472.
† *Physik der Sternatmosphären*, p. 269.

PRESIDENT: Dr M. MINNAERT.

SECRETARY: Dr D. BARBIER.

First meeting (Friday, August 13, at 10.30 a.m.).

The President reminded the Commission of the deaths of three of its members: Eddington and Fabry, whose contributions were outlined at the meeting of Commission 29, and E. G. Williams, whose achievements in the field of spectrophotometry of novae were outstanding; we shall remember him as an excellent member of this Commission.

The President intends to resign his functions after this assembly of the I.A.U. as is customary in this Commission.

Scope of activities. A survey of the whole field of spectrophotometry is not possible in future, said the President. The field is too comprehensive; it will be necessary to omit many special fields and to devote our attention primarily to spectrophotometry proper. Among the items in the Draft Report the President would suggest omitting the following: spectrographs; atomic transition probabilities; spectrophotometry of spots, flares, chromosphere, prominences; atmospheric lines; comets; corona; interstellar lines; nebulae; variable and abnormal stars.

Struve did not agree with this last point; he felt that it was not possible to draw the border-line between normal and abnormal stars, nor between variable and constant stars. Plaskett was not entirely satisfied with the idea of giving up transition probabilities to the Sub-Commission of Commission 14. Greaves emphasized that it is dangerous to forbid the President or the members to send reports on certain subjects; there should be left a certain freedom. D'Atkinson pointed out that the construction of spectrographs is correlated with the standardization devices, the losses of light, etc.

The President agreed that it is always very difficult to draw demarcation lines. But he thought that there was a general agreement for limitation. Therefore, although the President would be free to limit himself in writing his report, the members would still have the freedom to send contributions on related subjects.

Report of Commission. The President said that this report, held up on January 1, was not intended to review the publications of 1948. He thanked the members who had helped him by supplying information and contributions, and apologized for possible omissions.

It is very difficult to collect papers from certain countries. A short report from Hagihara (Japan) has just arrived. He, and his students, have worked out more than thirty papers on the theory of galactic nebulae. Japanese papers are available in the U.S.A. but not in other countries. Greaves suggested that the Executive Committee of the I.A.U. should be invited to write to the American Research Council, asking that one copy of each Japanese periodical should be sent to every country. According to Swings and Struve it would be safer to obtain film copies from an American observatory.

The President had received from the Optical Union seven copies of a paper by Rubinowicz dealing with multipole radiation, these being available for members interested in the subject.

As the results of an inquiry made by the President, it was ascertained that in most countries it is possible, after long delays, to get the necessary special photographic plates. The situation, therefore, is not good, but only tolerable. It thus seems unnecessary to take steps in this direction.

The President feared that there would not be much time left to discuss the other details of the Draft Report; he proposed that members, who wished to suggest modifications, should communicate with him. Lyman Spitzer then moved the adoption and Swings seconded. The Draft Report was then adopted.

Unit of line intensity. After the Stockholm meeting, the President invited the following scientists to form a Sub-Commission, in order to discuss the choice of a unit of line intensity: Dunham, Eddington, Menzel, Minnaert, Pannekoek, Plaskett, Russell, Struve and Unsöld. This Sub-Commission has not met, but work was carried on by correspondence and its

https://doi.org/10.1017/S0251107X00014048 Published online by Cambridge University Press

report issued in an Appendix of the Draft Report. Its aim had been to prepare the subject, leaving the decision to the Commission.

There is an amount of logic for each one of the systems proposed, said Menzel, but it seems that $\Delta\lambda/\lambda$ is generally more suited. Struve thinks that $\Delta\lambda$ is more appreciated by observers, but if theoretists prefer $\Delta\lambda/\lambda$ he is ready to make the divisions. The President suggested having two unities, $\Delta\lambda$ and $\Delta\lambda/\lambda$.

Struve would prefer that the Commission express a wish in favour of $\Delta\lambda/\lambda$, without forbidding $\Delta\lambda$. Greaves would agree if the wish were in favour of $\Delta\lambda$, without forbidding $\Delta\lambda/\lambda$.

The decision will be taken at the second meeting.

Infra-red spectrophotometry of the solar spectrum. Lectures on infra-red spectroscopy were given by Dr Struve (on behalf of Dr Kuiper), Dr Goldberg and Dr Migeotte. The President returned the thanks of the Commission to the lecturers. He had been very much impressed by the recent progress in infra-red spectroscopy which has been described and by the way in which different investigations complete each other. Struve emphasized that the discovery of methane in the earth's atmosphere by Migeotte had been a real sensation in America.

Second meeting (Tuesday, August 17, 9.30 a.m.).

Unit of equivalent width. From the report and from the previous discussion it has become clear that sometimes the one, sometimes the other of the two units has advantages, according to the problem in which they are used. This is the reason why there is no consensus of opinion among the members. Considering this situation, the President thought that it is impossible to impose one of the units and that they should both remain in use. Private discussions between the members of the Commission had shown that such a policy would be generally approved.

There remains the question of the symbols designating the *equivalent width* and the *reduced width.* Unsöld does not like the abbreviation $\Delta\lambda$ for an equivalent width, which is rather confusing for theorists; he would prefer A_λ. Menzel uses W_λ. Lyman Spitzer suggested writing $10^6 \frac{W_\lambda}{\lambda} = W_F$. Menzel objected that then the two units would differ only by the subscript; he suggested writing $10^6 \frac{W}{\lambda} = F$, W would be expressed in Ångströms and F in Fraunhofers.

The President proposed the following resolution, leaving to the Sub-Commission the question of designation.

Resolution. The Commission recognizes the usefulness of expressing line intensities in Fraunhofer units of $10^6 \frac{\Delta\lambda}{\lambda}$, as proposed by Dr Dunham and by the sub-commission on intensity units. However, it is of opinion that for many problems the ordinary units of equivalent width $\Delta\lambda$ retain their value. It asks that other units should be avoided unless in exceptional cases.

The resolution was accepted by the Commission.*

Creation of a Sub-Commission for the Establishment of a Standard system of Line Intensities. The President had received a letter from K. O. Wright suggesting the establishment of a uniform system of line intensities. This would necessitate, by a detailed intercomparison, the establishment of a system of standards for selected regions of the solar spectrum and for a few selected lines in certain stars. According to the President, the details are to be worked out by a sub-committee.

Greaves said that this proposition was premature and that the duty of the sub-committee should be to examine if it is time to take the proposition into consideration. Beals drew a parallel with the standards of radial velocities. The President suggested a sub-committee formed by Plaskett, Houtgast, Greenstein, Redman and K. O. Wright.

The Commission accepted his suggestion.

* After the meeting, the Sub-Commission decided: the equivalent width W shall be expressed ordinarily in milli-Angström (mA); the reduced width A shall be expressed in Fraunhofer (F).

https://doi.org/10.1017/S0251107X00014048 Published online by Cambridge University Press

Creation of a Sub-Commission for the Theory of Stellar Atmospheres. This second Sub-Commission should be very different, said the President. Our Commission is both theoretical and observational. At this meeting our activities have been more concerned with the observations, because in this field great progress is being made. At the next meeting it would be useful to devote more attention to theory and to have a sub-commission just to prepare these discussions; it did not seem advisable that the theoretical group should meet in a separate session. Greaves asked the President if he contemplated having also observers among the members of this Sub-Commission. The President thought that it ought to be rather constituted by theorists interested in observations.

Gratton agreed with the constitution of this Sub-Commission, but he suggested that an agreement could be reached with Commission 35 (Constitution of the Stars), which intends to extend its activities to stellar atmospheres. Kourganoff pointed out that theorists of stellar atmospheres are in many respects more interested in the work of Commission 36 than in that of Commission 35. The President has examined the question with Dr Milne, President of Commission 35, who fully agreed with the formation of the new Sub-Commission as proposed here. Greaves pointed out that the study of stellar atmospheres had progressed so rapidly because of the collaboration of theorists with observers. This subject is a classical example for inductive scientific research. It is important to co-ordinate and not to arrive at a divorce.

The President thought that theorists must have an outlet for their activity. The Sub-Commission could give a separate report and prepare a symposium for the next meeting of the I.A.U.

The creation of the new Sub-Commission was then adopted. The President proposed the members: Barbier, Chandrasekhar, Goldberg, Kosirev, Kourganoff, Menzel, Plaskett, Spitzer, Strömgren. Greaves suggested that the Sub-Commission could meet five minutes after the General Assembly to co-opt Dr Unsöld.

Joint Commission on Spectroscopy. The President read a proposition by the Commission Internationale d'Optique about the formation of a Joint Committee on Spectroscopy, together with members of the International Astronomical Union. For the time being, the purpose would be to co-ordinate work on term classification; in future the activities of this Joint Committee could be gradually extended.

Spectrophotometry of the Far Ultra-violet Solar Spectrum. Menzel gave a short lecture on ultra-violet spectrophotometry of the Sun with 'V 2' rockets.

The President returned the thanks of the Commission to Dr Menzel for his lecture on this spectacular subject and closed the session.

Abstracts of Lectures given at the Meetings of Commission 36

I. Spectrophotometry of Stars with Interference Filters.

Very promising results have been obtained by the use of interference filters and photoelectric photometry for spectral classification. Two interference filters isolating relatively narrow wave-length regions (width about 200 A.) around 4861 A. (H_β) and 4600 A. (comparison region) were used. For a number of stars of different spectral classes the ratio of the intensity through the H_β and the comparison filter, respectively, was measured with a photoelectric photometer attached to the 82-inch reflector of the McDonald Observatory. Results of nineteen measures of eleven stars on two successive nights are shown below:

Spectral class	B5	A0	A3	F1	G5	K2	M0
Intensity ratio H_β : Comp.	1·041	0·913	0·933	1·019	1·077	1·104	1·168

The effect of the absorption by H_β is clearly shown, superposed on a weak colour index effect.

From a comparison of the results obtained on different nights a mean error of the measured ratio corresponding to $\pm 0^{m}\cdot006$ (one observation) was determined. It follows that spectral classification based on the measured ratios can be effected with an accuracy of, for instance, better than one-tenth of a spectral class in the spectral ranges A5–F0 (provided rough classification is available to eliminate the B-star ambiguity).

The influence of selective interstellar absorption on the intensity ratio in question is not very pronounced. It might be eliminated by the use of three filters, or materially reduced through the use of narrower filters with maximum transmissions closer together.

The filters employed were manufactured by Baird and Associates, Inc. These filters reduce the intensity by about three magnitudes. Still narrower filters are now available, the application of which would undoubtedly lead to improved results. A systematic development of the method using several interference filters is planned.

The results mentioned were obtained in connection with a photoelectric survey of interstellar hydrogen emission carried out at the McDonald Observatory by W. A. Hiltner and the author (cf. this volume, p. 363).

B. STRÖMGREN

II. THE FAR ULTRA-VIOLET SOLAR SPECTRUM FROM 'V 2' ROCKETS

Scientific applications of the German 'V 2' rocket include studies of the far ultra-violet solar spectrum. Spectrographs, sent to heights above the ozone layer, have recorded the hitherto inaccessible region from 2875 to about 2000 A.

The observations, made at the White Sands Proving Grounds in New Mexico, have been largely undertaken by two experimental groups. Personnel from the Naval Research Laboratory include Richard Tousey, Ernst Krause, C. V. Strain and E. Durand. J. J. Hopfield and H. E. Clarman, Jr. have been most active in the second group from the Applied Physics Laboratory of Johns Hopkins University. Many other persons have contributed ideas and effort to the success of the project.

The Naval Research Laboratory group employs a concave grating in a modified Rowland mount. An image of the Sun, formed by a lithium fluoride bead, acts as a slit. Much of the light is wasted, because of the wide angle of the rays emanating from the bead. However, this wide angle is necessary so that the grating will be filled as the rocket rolls or yaws. Beads on opposite sides of the rocket nose provided two entrance slits, so that one is always turned toward the Sun. The automatic recording camera employs motion-picture film.

The spectrograph employed by the A.P.L. group was similar to the one just described above, except for the slit mechanism. This spectrograph employs a conventional slit, fed by an ingenious system of 'homing' mirrors, controlled by photoelectric cells.

Both groups have obtained excellent spectra, but none of the records extends appreciably beyond 2200 A. The general intensity of the background, throughout the new region, is very much less than that to be expected from a black body at 6000°. At 2200 A. the discrepancy amounts to a factor of 10.

Lines of Fe II are conspicuous through the entire region. There are also many stray lines of Fe I and several fundamental lines of Si I. The resonance line of Mg I, at 3780 lies close to the ultimate pair of Mg II, at 2796 and 2803. This doublet is scarcely resolved, but intense central emissions mark the positions of each Mg II line.

Low dispersion, lack of resolving power, and calibration problems make the interpretation of these spectra difficult. The general low intensity of the continuum, I believe, results largely from the overlapping wings of the numerous lines in the region. Nowhere do we find a completely clear window. A theoretical study indicates that wing absorption can play a role analogous to that of continuous absorption. Undoubtedly some continuous absorption is present, but from about 3700 A. toward the shorter wave-lengths the absorption by line wings dominates.

Curve-of-growth studies are almost inapplicable in this region. Interpretation of the spectrum in terms of abundances is a complicated problem, involving many uncertain factors, such as wing damping. The appearance of the spectrum suggests that only the very central cores remain for many lines. Theoretical calculations show that the equivalent widths of these lines should be many times greater than those measured directly from the tracing. The discrepancy must be attributed to the afore-mentioned weakness of the line wings.

The sharp central emissions in the Mg II doublet deserve some comment. They are, of course, analogous to the emissions H_2 and K_2 of Ca II. This emission undoubtedly arises in the Mg II flocculi, whose extent is appreciably greater than that from Ca II. We probably are to attribute both effects to a thicker chromosphere over the spot zones, increased temperature of the upper solar atmosphere, and high opacity at the line centre, so that we see down only into the hotter radiating layers. Theoretical considerations suggest that we should consider the process of line formation as one of absorption and re-emission rather than that of coherent scattering.

I wish to thank Drs J. A. Van Allen and J. J. Hopfield of the Applied Physics Laboratory, and Dr Richard Tousey of the Naval Research Laboratory, for their aid in assembling the exhibit of rocket photographs, which has been an interesting feature of the I.A.U. meeting.

DONALD H. MENZEL

A symposium on infra-red spectrophotometry was held, a report of which may be found on pp. 436–441.