12. COMMISSION DE LA RADIATION ET DE LA STRUCTURE DE L'ATMOSPHERE SOLAIRE

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La Commission a une Sous-Commission: 12*a*

INTRODUCTION

This report attempts to survey briefly the scientific activity in those areas of solar research assigned to Commission 12 during the period from the end of the tenth General Assembly to approximately 1 January 1961. It is based both upon reports received from members of this and related Commissions and upon a survey of the published literature, the latter source having been employed chiefly to report on the work of non-members of the Commission and of those members who neglected to submit reports of their work. Because of the short time available for its preparation, the report is neither critical nor complete but it is hoped that any major omissions can be rectified by the addition of an appendix prior to publication in the *Transactions*.

The elapsed time since the reorganization of the solar Commissions at the tenth General Assembly in Moscow has been too short to permit a full clarification of the detailed division of subject matter between Commissions 10 and 12. Although it is understood that in general Commission 12 deals with the properties of the undisturbed Sun and Commission 10 with solar activity, the assignment of many specific research topics to one Commission or the other is still not clearly indicated. Many of the subjects treated here could also be appropriately discussed either in one of the solar commissions or in the Commissions on Radio Astronomy, Magneto-hydrodynamics or Observations from Space Vehicles. Although the discussion of the same topic in more than one Commission is unavoidable and even frequently desirable, there is some danger that important researches will not be mentioned at all because each Commission President may assume that they are being treated elsewhere, and there has not been sufficient time for a full exchange of reports prior to publication.

The question of the most appropriate division of subject matter among the respective commissions should be discussed at a joint business meeting of the solar commissions at Berkeley. Further, Giovanelli suggests the organization of a co-operative effort between several observatories interested in studying time variations of chromospheric granulation. He points out that the larger-scale chromospheric structures last for the embarrassing period of between twelve and twenty-four hours, and are therefore rather hard to follow by any one observer. Another subject that seems timely in the area of international co-operation concerns the need for reports on the state of solar activity to be relayed continuously and rapidly to those astronomers who will be carrying out observations of the Sun from artificial satellites. It should be possible in the near future to direct the pointing of satellite telescopes and spectrometers to relatively small regions of the solar disk ($1' \times 1'$) by radio command, and the regions of interest can

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best be identified by ground-based observations on a world wide basis. This topic should be discussed in common with Commissions 10 and 44.

GENERAL

In addition to the references cited at the end of the Report, special attention should be drawn to a book entitled *Physics of the Solar Chromosphere*, which has been completed by R. N. Thomas and R. G. Athay and was published by Interscience Press, New York, in early 1961. The book contains a compilation of 1952 eclipse data together with analyses and theoretical discussion. Survey chapters on the Sun have been contributed to the *Handbuch der Physik*, Volume 52, by C. de Jager and by L. Goldberg and A. K. Pierce. A number of papers dealing with past and future solar experiments from rockets and artificial satellites have appeared in the *Proceedings of the 10th Astrophysical Colloquium*, held at Liège in July, 1960. Both the *Proceedings of the Varenna Symposium* (August, 1960), to be published as *Symp. IAU*, **12**, which was concerned with aerodynamical problems of stellar atmospheres, and of the colloquium *The Empirical Determination of Stellar Photospheric Structure* (July, 1959) which has been published by the Observatory at Uccle, also contain a number of papers relating to the Sun.

SOLAR CONSTANT AND APPARENT MAGNITUDE

The revision of existing data has led to a value of —26·73 for the apparent solar magnitude in the Harvard system (1). The question of the constancy of the solar constant continues to be somewhat controversial. Sterne and Dieter (2) have carried out a statistical analysis of Smithsonian measures of the solar constant over a period of thirty years from Montezuma, Chile and from Table Mountain, California, finding that the standard deviation of real changes is less than 0·17% with no periodicities common to both stations. Abbot (3) still favors the idea that both sporadic and periodic variations in the solar emission occur, and Aldrich and Hoover (4) find evidence for small irregular variations in the solar constant not exceeding 2%, the most probable absolute value being 1·94 langleys per minute. Photo-electric measurements on Uranus and Neptune by Johnson and Iriarte (5) imply an increase of about 2% in the output of blue radiation from the sun in the period from January, 1953 to July, 1958.

SPECTRAL ENERGY DISTRIBUTION AND LIMB DARKENING

New measurements of absolute intensity and of spectral energy distribution have been carried out in a number of wave-length regions, particularly in the infra-red. Pierce and Waddell (1) have observed both the energy distribution and limb darkening in the solar spectrum from λ 3100 to λ 24 000 at the McMath-Hulbert Observatory. Saiedy and Goody (2) have made an accurate measurement of the intensity at the center of the disk at 11·10μ by direct comparison with a black body at 1300 °K. During the summer of 1960, Houtgast used the Snow telescope and photo-electric spectrometer at Mount Wilson to record the solar spectrum from 3000 Å to 4000 Å with sufficiently high resolving power to establish the run and absolute height of the continuous spectrum to a fair degree of accuracy. Solar radiation measurements at all wave-lengths from the visible to 2·5μ have been carried out from a balloon to an altitude of 100 000 feet for the purpose of deriving the amounts of H_2O and CO_2 above each height in the atmosphere (3). Sitnik (4) has devised a model of a black body and used it for absolute measurements of intensity distribution in the solar spectrum. Peyturaux reports the construction and installation of a new observation station at Montlouis (Pyrenees) at 1600 meters altitude, primarily for the absolute measurement of the continuous background of the solar spectrum at the largest possible number of wave-lengths. Absolute intensities will be derived by direct comparison with a black body at about 2600 °K. The first observations were

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made during the summer of 1960 and reductions are in progress. A theoretical investigation by Unsöld (**5**) shows that the break in the relative energy distribution of the Sun minus a B-type star near 4800 Å is due to increasingly crowded lines in the blue and violet part of the solar spectrum, contrary to the findings of Chalonge and Kienle.

Kojevnikov (**6**) and Stepanov (**7**) have studied solar limb darkening, the former in the spectral region 1—4μ, and the latter in six ultra-violet and visual wave-lengths. Several determinations of darkening at the extreme limb have been made during observations of total, partial and annular eclipses, by Rubin (**8**) in a 2000 Å wave-length band centered on 8000 Å, by Neckel (**9**) at 4674 Å and by Saito and Hata (**10**) at 4700 Å. All of these measurements refer to the outer 2% of the solar radius. Similar measurements have been made with a coronagraph in a 3 Å band of the continuum near Hα by Dunn (**11**). Photographs made during the 1957 Stratoscope balloon flight have been used by Rogerson to extend the intensity distribution to within 1″ of the limb (**12**). In connection with a general survey of the limb darkening of stars, F. van 't Veer (**13**) showed that the solar limb darkening may be described rather accurately by the following formula:

$$\mathcal{J}/\mathcal{J}_c = 1 - v(1-\mu) - v^1(1-\mu)^3$$

MAPS AND TABLES OF THE SOLAR SPECTRUM

Minnaert reports the completion of the co-operative project of Mrs Sitterly and the Utrecht Observatory for the revision of the Rowland table. Preparations for printing are now being made but a pre-publication of the photometric data has already been issued (**1**). This important catalog contains equivalent widths of Fraunhofer lines observed in the center of the solar disk, based primarily upon the Utrecht atlas, but with the valuable addition of wave-lengths between 3100 Å and 3650 Å from spectrograms made by M. T. Brück and Thompson at the Dunsink Observatory. A new atlas of the ultra-violet spectrum of the Sun at cos θ = 1·0 and 0·2 and from 2988 Å to 3629 Å has been prepared by G. Brückner from concave grating spectra at Göttingen. The atlas will shortly be published by Vandenhoeck and Ruprecht, Göttingen, as a separate volume of the *Abhandlungen der Akademie der Wissenschaften* in Göttingen.

Migeotte reports on the installation of a new spectrometer of the Ebert-Fastie type at the International Scientific Station of the Jungfraujoch (Switzerland) at an altitude of 3580 meters. The focal length of the spherical mirror is 7·30 meters. The instrument is equipped with an original Babcock grating blazed at 2·8μ (15 000 lines per inch—dimensions of the ruled surface 13 × 20 cm) and a 13-stage infra-red Lallemand photo-multiplier. The first observations are leading to the preparation by L. Delbouille (**2**) of a photometric solar atlas covering the spectral region 7500–12 000 Å, consisting of about 160 plates covering about 30 Å each.

The details of the ultra-violet solar spectrum observed from rockets are gradually being established with the publication of a number of tables of wavelengths, intensities and identifications in the following spectral regions: 2471–2937 Å (**3**), 2471–2635 Å (**4**), 1800–2600 Å (**5**), 1032–1893 Å (**6**) and 1206–1817 Å (**7**). Special mention should be made of a newly-published photometric atlas of the rocket ultra-violet from 1800–2965 Å based upon the observations of Rense and his collaborators (**8**).

WAVE-LENGTH MEASUREMENTS

Precise measurements of wave-lengths have resulted in numerous reports of research dealing with the relativity red shift, solar rotation and circulation and the identifications of selected lines.

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Relativity Red Shift

Adam and Nichols (**1**) established the accuracy of the red shifts measured by circular-channel interferometry as better than 0·001 Å. Papers by Miss Adam on red shifts at the center of the disk (**2**) and on the so-called limb effect (**3**) throw doubt on the interpretation by Schröter (**4**) of residual red shifts in terms of radial currents. Miss Adam's results have been supported by Higgs (**5**) who finds both a super-relativity red shift at the limb and evidence for marked asymmetries of the lines at the limb. The asymmetry is being investigated in more detail by Higgs. L. Herzberg (**6**) has presented new measurements of the wave-length displacements between limb and center of the Sun for lines of Fe I, Si I and Ca II in the 8500 Å and 8900 Å regions. Finlay-Freundlich and Forbes (**7**) discuss further their hypothesis that the solar red shifts are compatible with a new empirical law but the physical basis of their formula is unclear. In view of the laboratory experiments on the Mössbauer effect (**8**) there no longer seems to be any reason for doubting the presence of a gravitational red shift in the solar spectrum. The real problem now would seem to be to account for the remaining residuals between solar and laboratory wavelengths after the Einstein shift has been subtracted.

Rotation and Circulation

The velocity of solar rotation in latitudes between 40°–50° has been determined from sunspot groups by Kopecky (**9**) and at higher latitudes between 61°–76° from observations of faculae by Müller (**10**). The change in the character of the solar rotation with depth has also been studied by Rubashev (**11**) and Kopecky (**12**). Meadows (**13**) draws attention to the discrepancy between the theory of iso-rotation and the observation that chromospheric lines show higher angular velocities than photospheric lines.

Some 332 measures of radial velocity over the surface of the Sun have been analyzed for rotation and meridional currents by Plaskett (**14**). The hypothesis that these currents and the equatorial acceleration are the result of a thermal wind due to polar cooling will be tested by measurements of limb darkening at the equator and the pole. According to Kippenhahn (**15**), hydrodynamical considerations of the hydrogen convective layer require that the circulation flows toward the pole in agreement with filament motions and with Plaskett's analysis. In this connection, Beckers (**16**) has found a dependence of Fraunhofer line intensity upon latitude which suggests a temperature maximum at the poles and a minimum at a latitude of 45°. A comparison with measurement of other authors shows, however, that there is probably an eleven-year periodicity in the latitude effect. Proper motions in latitude have also been examined in (**17**) and (**18**). Rubashev and Svechnikova (**19**) have shown that turbulent conductivity leads to a decrease of interaction between electromagnetic and hydromagnetic forces in the convective zone of the solar atmosphere which is favorable to the occurrence of stationary motions in this zone. Chistjakov (**20**) finds that the velocity of meridional circulation determined by means of Spörer's Law has a sharp minimum 1·5 years after the maximum of the solar cycle.

Identifications of Selected Lines

A detailed investigation on the presence of CH lines in the solar spectrum has been carried out at the U.S. National Bureau of Standards in connection with the program for the Revision of the Rowland Tables (**21**). An attempt by Nikitin (**22**) to identify lines in the solar spectrum usually attributed to technetium with lines of other atomic and molecular spectra, yielded negative results. New identifications of a number of coronal lines observed by Aly at the Khartoum eclipse have been derived by C. Pecker (**23**) on the basis of new and systematic calculations of iso-electronic sequences in the range 200–800 eV and λ 3300–λ 6800. In the

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same paper the identification of λ 5694 and λ 5446 with Ca XV is further strengthened, and is confirmed also by Borisoglevsky (**24**).

From rocket photographs of the far ultra-violet spectrum obtained by Rense and Violett, C. Pecker (**25**) concludes that both resonance lines of Mg X seem to be present. Identification of the strong line at λ 344·7 in terms of the O III ion is disputed. An alternative identification in terms of the resonance transition in Fe X is proposed but the presence of the second line of this multiplet has not been confirmed.

INTENSITIES AND PROFILES OF FRAUNHOFER LINES

Miss Hart (**1**) has developed methods for correcting the effects of atmospheric and instrumental distortions on the observed profiles of solar lines near the extreme limb.

At Göttingen, the profiles of the Balmer lines Hα–Hδ have been observed photo-electrically by K. H. David (**2**). The lines show wider wings than in all earlier photographic investigations. The center to limb variation of the wings can be well understood by Kolb's extension of the Stark broadening theory including resonance broadening, using a homogeneous or inhomogeneous model atmosphere. The model employed by David, which well represents the Balmer lines, has been derived in collaboration with G. Elste as a slight modification of the Aller-Pierce-Waddell model. Also at Göttingen, Th. Schmidt has carried out photographic and photo-electric observations in the second order of the concave grating for the determination of the center to limb variation of the copper resonance lines λ 3247 and λ 3248.

The profiles of several interesting Fraunhofer lines in the infra-red were studied at the Jungfraujoch by de Jager and Neven. Only a very small asymmetry was found in the oxygen lines λ 7772–5. A similar investigation of the line profiles of the infra-red oxygen triplet is currently being pursued by Miss Müller at Michigan with observations by Mitchell at the Snow telescope on Mount Wilson. Variations of the sodium doublets λ 5685 and λ 8190 along a solar radius have been studied by Rigutti (**3**). E. v. P. Smith (**4**) has made a detailed examination of the emission cores of the H and K lines on the normal disk and in plages.

Waddell has made new and very precise observations of the profiles of the D lines and their center-limb variations with the double-pass optical system of the thirteen-meter spectrograph of the Sacramento Peak Observatory. A preliminary analysis shows that there is no detectable difference in the source function for the two D lines. Other observational programs in progress at Sacramento Peak include the observation of line profiles in flares with the universal spectrograph in the region 3600 Å to 7000 Å (dispersion 2 Å/mm), local Doppler shifts and variations in the profiles of Fraunhofer lines, and line profiles for the infra-red lines of calcium.

Equivalent Widths, Central Intensities and the Curve of Growth

Nearly all recent studies of the equivalent widths of Fraunhofer lines have included observations at the limb as well as at the center of the disk. Comparisons of the curves of growth at center and limb have been made by Teplitskaya (**5**) for neutral and ionized iron and titanium and by Sankaranarayanan (**6**) for neutral titanium. The center-limb variation of the intensities of selected solar lines in the wave-length region 5780 Å–21225 Å have been compared by Mitchell (**7**) with the predictions of various models. Ten Bruggencate (**8**) has investigated certain aspects of the theoretical curves of growth for lines formed in pure absorption by the method of weighting functions. Suslov (**9**) has studied the relation between the equivalent width and the product of the half-width and height of the profile.

Studies of the center-limb variations of the central intensities of Fraunhofer lines reveal the presence of the so-called 'fishbone' effect (**10**) found earlier for the Balmer lines by Athay and

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Thomas. The effect is attributed to the influence of inhomogeneities in atmospheric structure. From a study of about 2000 absorption lines, Melnikov (**11**) finds that the central intensities increase nearly linearly with wave-length between 4000 Å and 7000 Å. The mean damping constant also appears to vary with wave-length.

OBSERVATIONS OF UV, X-RAYS AND GAMMA RADIATION

A review by Ivanov-Kholodny (**1**) lists seventy-nine references to investigations of short-wave solar radiation carried out from rockets through the period of the IGY. However, developments in this field are proceeding so rapidly that any published review, including the present one, is likely to be out of date by the time it appears.

Spectral Surveys of UV Spectrum

A report of the newest results obtained by the U.S. Naval Research Laboratory was presented at the tenth Astrophysical Colloquium at Liège, July 1960, and appeared in the *Proceedings* (**2**). New spectra obtained in 1959 and 1960 with greatly reduced stray light show about 200 emission lines to a short-wave limit of 499 Å. The extension of the continuum from longer wave-lengths has been observed to about λ 1000. Eleven members of the Lyman series and its continuum have been observed. The spectrum consists chiefly of lines of the abundant light elements through sulphur, many ionization stages being represented. Still shorter wave-lengths extending below 100 Å have been photographed in 1958 and 1959 by Violett and Rense (**3**). In addition to λ 304 of He II, and λ 584 of He I, the photographs show a wealth of emission lines, many of which have been identified (**4**). Ivanov-Kholodny (**5**) investigated the ultra-violet Mg II lines and found no dependence of their intensity upon solar activity.

Up until recently, all surveys of the ultra-violet solar spectrum from rockets made use of photography, which is not feasible for satellite application. An important step towards satellite spectroscopy has been taken by Hinteregger (**6**) in several flights of a grazing-incidence scanning monochromator and a magnetically focussed photo-multiplier. The range of the scan is 60–1300 Å, with a resolving power of 10 Å. The records show λ 584 He I, λ 304 He II and λ 256 He II as well as the Lyman continuum and the He^+ continuum beyond 228 Å.

Intensity and Profile of Lyman-α

Following earlier indications of large variations in the solar Lyman-α intensity, a series of seven measurements with an ion chamber between 1955–8 has yielded remarkably consistent results averaging about 6 ergs/cm^{2}sec for the flux at the top of the Earth's atmosphere (**7**). One of the most brilliant achievements in rocket spectroscopy has been the photography by Purcell and Tousey (**8**) of the profile of solar Lyman-α with a resolving power of 40 000. Contrary to earlier work by the Naval Research Laboratory, the line is quite broad with wings extending to 1 Å on either side of the line center. The core of the line shows a broad shallow absorption of solar origin and a narrow deep absorption core which probably arises from absorption by neutral hydrogen in a geocorona. About 2×10^{12} hydrogen atoms per cm^2 are estimated to lie between a height of 100 km and the Sun. An echelle grating of still higher resolving power will be employed in later flights.

Lyman-α Images of the Sun

Remarkable monchromatic photographs of the Sun in Lyman-α have been obtained, also by Purcell and Tousey (**9**), with a double-grating monchromator and an angular resolving power of about 30″. Future flights are planned in which photographs will be attempted in Lyman-β and in the O VI lines 1032, 1038 Å.

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Measurements of X-rays and Gamma Rays

Measurements made during the eclipse of 1958 October 12, (**10**) show that solar X-ray emission originates so high in the corona that it is not entirely obscured at totality. The emission is closely associated with active regions on the Sun. The observed limb brightening agrees rather well with the predictions of Elwert. The first X-ray image of the Sun (**11**), made with a pinhole camera, indicates that the X-ray emission from plage regions is about seventy times greater than that from the quiet background. The observed limb brightening also appears to favor line emission rather than continuous emission as the source of the radiation. The solar emission of both X-rays in the band 2-8 Å and of Lyman-α are being monitored from the satellite 1960 Eta 2, which was launched in the spring of 1960, together with the U.S. Navy Transit II-A navigational satellite (**11**).

As a prelude to similar experiments that will be attempted from satellites, a γ-ray telescope has been flown from a balloon at 80 000 feet in an attempt to detect energetic radiation from the Sun (**12**). No positive results were obtained during forty minutes on 1957 October 18, but the upper limit for the flux of photons with energies greater than 200 Mev was 0·008 per cm^2 sec, or about 1% of the cosmic ray flux.

INVESTIGATIONS OF THE PHOTOSPHERE

Granulation

The advent of balloon observations and the improvement of techniques connected with ground-based observations have been extremely productive in refining the quality of granulation photographs, with the result that one may now look forward with considerable confidence to the achievement in the near future of an accurate description of the granulation and its time dependence. Following the first successful flights of a 12-inch solar telescope to a height of 80 000 feet in a balloon in 1957 (**1**), Schwarzschild reports as follows:

'During the summer of 1959, four more balloon flights were carried out with the 12-inch solar balloon telescope first flown in 1957. Prior to these flights the instrument had been improved by reducing the mechanical vibrations, by adding a television channel so that the pictures of the solar surface as they were being photographed in the stratosphere could be watched in a mobile ground station, and by adding a radio command channel through which the astronomer in the ground station could at will change the focus as well as the position on the Sun of the area being photographed. Time sequences of high-definition photographs were obtained both for the granulation and for some sunspots.

'While the auto-correlation in space of the intensity in the solar granulation had already been determined from balloon photographs obtained in 1957, Bahng and Schwarzschild have used the best time sequence obtained in the new flights to determine the auto-correlation in time of the intensity of the solar granulation. From these data the average lifetime of granules (defined as twice the time interval in which the auto-correlation drops to one half) was found to be eight minutes.

'Danielson has used the new balloon photographs to investigate the photospheric features of sunspots. He has concluded that the typical penumbral filaments are most likely convective rolls.

'Rogerson and Gaustad are redeterming the solar limb profile on the basis of the best limb photographs obtained in the new flights and are at the same time measuring the brightness contrast in flocculi near the limb.'

Additional results from the 1957 Stratoscope flights have been reported by Edmonds (**2**) and by Bahng (**3**).

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On the basis of observations from a manned balloon at 18 000 feet altitude, Blackwell *et al.* (4) have found that the corrected mean contrast between the granules and the intergranular regions is 40% at a wave-length of 5300 Å. The true rms brightness fluctuation was found to be 18%. Their conclusion has been challenged by Gaustad and Schwarzschild (5) who show that a more detailed analysis gives a true rms brightness fluctuation of about 7%, in agreement with Schwarzschild's earlier determination (1).

Recent work in France and in Australia has demonstrated that valuable results may also still be obtained from the ground with careful observational techniques. From the Pic du Midi, Rösch writes as follows:

'A la suite des résultats encourageants obtenus dans l'observation de la photosphère au moyen d'un objectif de 23 cm (6) on a mis en service un réfracteur de 38 cm et 6 m de longueur focale. Cet instrument a permis fréquemment d'obtenir des images montrant sur la granulation les mêmes détails que les photographies obtenues par Schwarzschild *et al* au moyen d'un ballon télécommandé a l'altitude de 24 000 m. Il a notamment été possible de réaliser un film cinématographique montrant l'évolution des granules pendant une période d'une demi'heure, et mettant en évidence, en particulier des fragmentations d'allure irréversible (7). On a également entrepris de photographier le même champ granulaire presque simultanément en deux domaines de longueurs d'onde différents (4600–4640 et 6150–6250) les premiers résultats n'indiquent aucune différence manifeste de structure.

'En vue d'améliorer le rendement de ces observations, on a réalisé un dispositif qui, par filtrage des effets dus à l'atmosphère terrestre et mesure photo-électrique du contraste des granules est capable de déclencher une pose photographique au moment où la qualité de l'image dépasse un certain seuil (8).'

A major program of research on solar granulation is in progress at the National Standards Laboratory of the CSIRO, Sydney, Australia as reported by R. G. Giovanelli:

'The evolution of photospheric granules has been followed using a 5-inch photoheliograph (9). The photoheliograph was designed for high-resolution time-lapse cinematography and was equipped with a seeing monitor which automatically triggers the shutters when the seeing is better than some pre-determined acceptable level (10). The photospheric granules show a considerable diversity in brightness, size and shape, over half of them showing no detectable changes during the periods over which they persist as identifiable structures (11). In agreement with Macris (12) the lifetime is found to be of the order of ten minutes—considerably greater than earlier estimates had indicated. The "cell size", defined as the average distance between the centres of adjacent granules, has been measured for both the photospheric and umbral granulation, the mean values being 2″·9 and 2″·3 respectively (13). The relatively narrow distribution of cell sizes found and the stability of the majority of granules indicate a convective origin for the granulation, as against fully developed turbulence (14). There is no evidence for the very small, very bright granules which were a feature of the turbulent theory of granulation, bright granules being larger just as commonly as smaller than average. In agreement with Rösch's conclusions (15), the photospheric granulation is found to persist to within 4″ from the limb (16).'

Macris (17) is investigating the possible dependence of granular size on wave-length. Fellgett (18) has summarized the difficulties inherent in the interpretation of observations of solar granulation and has emphasized the importance of modernizing interpretive techniques to handle the new and relatively sophisticated observational data. An attempt by Steshenko (19) to measure the magnetic fields of separate granules leads to the conclusion that such fields, if they exist, do not exceed the mean accidental error of ± 50 gauss.

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Three theoretical investigations of the hydrogen convection zone should be mentioned, the first (**20**) containing numerical calculations of several models of the hydrogen convection zone, the second (**21**) an investigation of the turbulence spectrum of thermal convection and the third (**22**) pointing out difficulties in the assumption that the mixing length is equal to the scale height and giving a detailed theoretical description of the solar hydrogen convection zone. Whitney (**23**) argues that motions in the solar atmosphere cannot be pure compression waves but must be thought of as a mixture of compressional and gravitational waves. Giovanelli (**24**) and Wilson (**25**) have been studying radiative transfer in non-uniform media with the ultimate aim of interpreting physical conditions in granules and sunspots.

General Magnetic Field

Continued systematic observations with solar magnetographs are beginning to clarify the nature of the Sun's general magnetic field and its variability. According to H. D. Babcock (**26**) the polarity of the field near the south heliographic pole underwent a reversal about the middle of 1957; the north polar field was reversed in November, 1958. Babcock's results as to the polarity and intensity of the Sun's polar field have been confirmed at Cambridge (**27**), with a new magnetograph for the automatic recording of very weak magnetic fields which has been constructed and put into operation by von Klüber and Beggs. A new model of the Sun's magnetic field, based on observations with the magnetograph over several years and including a synthesis and extension of current theories by Cowling, Parker and others has been proposed by H. W. Babcock. The model accounts for the reversal of the main dipole, for the sunspot polarity laws, and for a number of other incidental features.

A hydromagnetic model of the solar magnetic field has also been derived by Csada (**28**) from the Babcock magnetograms and the form of the polar rays of the corona. From the forms of the polar rays during the 1954 and 1955 eclipses, Shimooda (**29**) concludes that the general solar magnetic field differs from that of a magnetic dipole.

Magnetograph records in the D_1 line of Na and the H_3 line of Ca^+ have been used by Stepanov (**30**) to determine the gradients of magnetic field strength in undisturbed regions of the photosphere and chromosphere. The orientation of the magnetic field of sunspots may now be measured by use of a Babinet compensator (**31**). Originated by Treanor, the method is being further investigated at Oxford by Miss Adam. The Sun's polar magnetic field may be deduced indirectly from the scattering of radio waves by the solar corona when it occults the Crab nebula. In this way, Hogböm (**32**) obtains the value 1·5 gauss, in good agreement with the Mount Wilson measurements.

Motions

A full understanding of the nature of convection in the solar atmosphere requires careful study of the velocity fields revealed by Doppler shifts in the lines as well as of the brightness fluctuations in the continuum. The connection between line shift and brightness fluctuation is still very unclear but evidence is beginning to accumulate that the observations cannot be described by the simple classical picture of bright elements rising and dark elements falling. The interpretation of observed local Doppler shifts is greatly complicated by the now well-established bright-dark asymmetry of the granulation (**1**) which, when coupled with imperfections in seeing, tends to make the observed line shifts refer chiefly to the bright regions. In this connection, it should be pointed out that if the reality of the Einstein gravitational shift is accepted, determinations of the rms velocity do not refer to averages over rising and falling elements but in effect measure the dispersion of preponderantly upward velocities. In future measurement programs, it would be highly desirable to include lines for which absolute wave-

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lengths have been determined, in order that the shifts may be referred to the undisplaced position of the line rather than to its observed center of gravity.

New measurements of local Doppler shifts in photospheric Fraunhofer lines (**33**) and (**34**), which refer to elements of 5″ size, prove that the rms velocity increases toward the limb and that the increase is more pronounced for the weaker lines than for the stronger ones. The fact that the velocity dispersion tends to increase with line strength suggests that the limb effect results from an increase in rms velocity with height. Michard reports as follows on the recent and current work of Servajean:

'Grâce à la haute qualité des images au Pic-du-Midi, de nombreux spectres à grande résolution de la surface solaire ont été obtenus en 1959–60. Quelques-uns ont une définition comparable à celle des bons clichés de la granulation photosphérique (meilleure que 1″). L'inspection de ces spectres et une première analyse quantitative par R. Servajean (**35**) montrent que le champ des vitesses turbulentes dans la photosphère résulte de la *superposition* d' 'elements' de toutes dimensions entre 1″ et 15″, contrairement à la granulation ou dominent les éléments de 1″ à 2″ (d'après les mêmes documents). Les effets Doppler rouges sont en général associés aux éléments sombres de la photosphère et réciproquement, mais seulement pour les éléments de 1″–2″; il n'y a pas de corrélation quantitative entre brillance et déplacement Doppler.'

The effects of bad seeing can be greatly minimized by shortening exposure times through the use of electronic imaging devices. This approach is being followed by G. Wlérick, who reports that:

'La caméra électronique de A. Lallemand, dans la version réalisée par Lallemand et Duchesne, est un récepteur très perfectionné qui permet un gain important en temps de pose sans perte de définition ni autre phénomène parasite.

'J'ai entrepris en collaboration avec Mlle M. F. Dupré, des essais de spectroscopie des structure fines du Soleil avec la caméra électronique adaptée au spectrographe de R. Michard à l'Observatoire du Pic-du-Midi. Avec des temps de pose de l'ordre de 1/10ème à 1/20ème de seconds, on obtient des spectres de très bonne qualité et je pense que si nous arrivons à prendre des spectres aux moments où la qualité des images est effectivement très bonne, il sera possible d'obtenir des clichés bien adaptés a l'étude des structures fines.'

Miss E. A. Müller is engaged in an investigation of the velocity and temperature fields in the solar atmosphere as revealed by the Fraunhofer lines Na D_1 and the nearby medium strong Ni I line at λ 5892·9, employing high dispersion spectra secured with the vacuum spectrograph of the McMath-Hulbert Observatory. Similar studies are under way by Evans and his associates at the Sacramento Peak Observatory.

Important results on the radial velocity field over undisturbed regions of the solar disk have been obtained by Stepanov (**36**) with the aid of the solar magnetograph and radial velocity recording device of the Crimean Solar tower. He finds extensive regions in the chromosphere (up to 2×10^5 km) over which predominantly ascending or descending motions exist. Inside these regions irregular motions with characteristic size of elements from 5000–20 000 km and lifetimes of about seven hours are observed. The mean velocities of ascending and descending motions are −0·96 and +1·25 km/sec.

The Doppler widths of photospheric lines have been analyzed by Unno (**37**). If the non-thermal component is attributed to turbulence, the turbulence is found to increase with depth, in agreement with earlier results by Suemoto. Bell and Meltzer (**38**) have published a new analysis of the Doppler widths of twenty-two lines of elements of different atomic weight in support of their contention that the line widths are not compatible with a kinetic temperature significantly below 10 000 °K.

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Polarization Studies

The continuous radiation from the photosphere has been found to be slightly polarized (**39**), the degree of polarization increasing from the center to the limb, where its value is a few parts in 10^4. The polarization also increases toward shorter wave-lengths and is diminished in faculae but enhanced in prominences.

Jäger (**40**) has made new calculations of the polarization of radiation in the centers of absorption lines formed by coherent scattering and obtained good agreement with new observations of Ca I λ 4227 at center and limb.

Models of the Photosphere

This section is concerned with the investigation of solar photospheric models determined either empirically from continuum or line observations or theoretically from considerations of radiative, adiabatic and convective equilibrium. As limb darkening observations are carried ever closer to the extreme limb it becomes important to take account of curvature effects on their interpretation. Proisy (**41**) finds that the effect results in a reduction of the derived boundary temperature by about 100 °K. A new temperature model of the photosphere, derived by Pagel (**42**) from limb darkening, shows a temperature minimum with a value of 4300° ± 100 °K at optical depth 0·007 ± 0·002. The integration of a new pressure model at near infra-red wave-lengths by Mitchell (**43**), with a reduced metal abundance log $A = 4{\cdot}28$, leads to electron pressures about 50% lower than those of the Aller-Pierce model. Böhm and Böhm-Vitense (**44**) use Rogerson's balloon measurements of the center-limb variation at λ 5400 to study the influence of the Fraunhofer lines on the temperature distribution in the Sun's outer layers.

The center to limb variations of the profiles of the two infra-red Ni lines λ 7789, λ 7798 have been measured by Voigt (**45**) and interpreted in the context of his inhomogeneous model. Unfortunately, compensatory effects on the line profiles make them nearly symmetrical and therefore work against a positive test of the model. The Kolb theory of Stark broadening has been applied by Mugglestone (**46**) to the prediction of the profile of the far wing of the Hγ absorption line on the basis of the three solar models of Claas, Vitense and Swihart. Agreement with the observed profile is achieved best with the Swihart model.

Model of the normal photosphere and of a sunspot have been examined by Laborde (**47**) in the light of the center-limb variation in the intensities of molecular bands of MgH, C_2, CH, CN, OH and NH. The analysis is complicated by uncertain knowledge of dissociation energies and oscillator strengths, but it appears that no actual model of the photosphere can account for the observed center-limb variation of the intensity of the bands of C_2 and MgH. The pressure in sunspots seems to be greater than indicated by Michard's model. From the central intensities of metallic lines, Neckel (**48**) derives the temperature distribution in the outer layers of the photosphere, finding a boundary value of about 3600 °K at optical depth 10^{-5}. The results are similar to those obtained earlier from the central intensities of the Balmer lines, a procedure which has been criticised by Athay and Thomas (**49**) on the grounds that the centers of strong Fraunhofer lines are not formed in local thermodynamic equilibrium (LTE) and hence cannot be used to derive the electron temperature distribution. Tomita (**50**) has computed the profile of the Na D_1 line for the two cases of coherent and non-coherent scattering and compared them with observation in relation to the two models, I and II, proposed by Vitense. A model of the photosphere of a sunspot has been deduced by Berdichevskaja (**51**) from a comparison between observed and calculated equivalent widths of lines of Mg I, Ca I and Al I.

Krook and Pecker (**52**) have improved the convergence of Strömgren's iteration method for the calculation of atmospheric models in radiative equilibrium in the non-grey case. Adiabatic

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and minimum convective models of the Sun have been calculated by Swihart (**53**) and compared with observation. The problem of the structure and dynamics of the outer layers of the Sun has been reconsidered by Wasiutynski (**54**) with special attention to the role of rotation.

Abundances

The subject of solar abundances continues to be beset with difficulties arising from uncertainties in *f*-values and in the measurement of faint lines of heavy elements in the solar spectrum, and from the possible introduction of large errors caused by departures from local thermodynamic equilibrium. Many of these difficulties are discussed in the course of a detailed and critical redetermination of the abundances of forty-two elements from their faint and medium strong lines in the solar spectrum (**55**). Special investigations of the solar abundances of lead (**56**), thorium (**57**), iron (**58**) and nitrogen (**46**) have also been carried out. Mugglestone (**59**) concludes that the determination of abundances from faint lines by the method of weighting functions is unreliable for atoms of high ionization potential and proposes an alternative method. Hubenet (**60**) has studied the influence of the adopted solar model on abundance determination and the helium content. It appears that the combined influences of uncertainties in these factors amounts at most to a factor of two and that other uncertainties, *e.g.*, in the transition probabilities, are much more important. Pecker (**61**) estimates that the assumption of LTE leads to an underestimate of the abundance of titanium by a factor of five. E. A. Müller is conducting an investigation on the effects of deviations from LTE on solar abundances by investigating the observed center-limb variation of the curves of growth of elements in the iron group. A revision of the abundance table of Suess and Urey to make it consistent with calculations of nucleo-genesis by Cameron (**62**) has been criticised by Burbidge (**63**) as premature. It appears to be a matter of opinion as to the relative weights to assign to abundances predicted from the data of nuclear physics on the one hand and those determined 'observationally' from the stars or meteorites. Considerations of the mechanism of origin of the solar system have led to the suggestion that the outer envelope of the Sun was once highly abundant in lithium (**64**). Aller and Chapman (**65**) have estimated the rate of downward diffusion of the heavier ions from the convective zone and have shown that the diffusion reduces the abundances of heavy elements relative to hydrogen in the Sun's atmosphere and also affects their relative abundances.

Theoretical Studies

This section contains references to theoretical studies that have a bearing on the calculation of line and continuous spectra of the photosphere. New calculations on the free-free (**66**) and bound-free (**67**) absorption coefficients of the negative hydrogen ion emphasize the importance of allowing for exchange effects. Interpolation tables (**68**) have also been computed to permit readout of the tables by Chandrasekhar and Breen at very small intervals of wave-length and temperature. Pagel (**69**) has shown that the dissociation of H^- by electron impact is negligible in the solar photosphere as compared with photo-electric dissociation, but that nevertheless associative detachment by collision with neutral hydrogen is sufficient to maintain LTE. Przybylski (**70**) investigates the accuracy with which various types of mean absorption coefficients may be used to compute non-grey model atmospheres for solar-type stars.

New methods for the solution of the transfer equation have been developed both for a non-grey atmosphere (**71**) and for a grey atmosphere including the blanketing effect (**72**). Sobolev (**73**), in a series of papers, has developed a method for the solution of the problem of radiative diffusion using the theory of probability. The same methods are used by Minin (**74**) to solve non-steady state transfer problems.

A substantial amount of activity has been devoted to the theoretical calculation (and in

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some cases measurement) of atomic parameters relative to the theory of line profiles and intensities, to the investigation of departures from local thermodynamic equilibrium to the development of new methods for the calculation of line profiles, etc. New methods for the calculation of cross sections for collision have been developed by van Regemorter (**75**) and applied to the ions Ca II and Mg II. Other ions are being studied. New oscillator strengths have been determined for Ti II, based on the unpublished measures of Meggers (**76**). Special attention is being devoted to the computation of transition probabilities and collisional cross sections for many of the ultra-violet lines accessible from rockets and satellites (**77**). New tables of Stark broadening functions for the Lyman, Balmer, Paschen and Brackett series have been published by Underhill and Waddell (**78**) and employed for the calculation of thermally-broadened Stark profiles of several high Balmer lines by Jefferies (**79**). Related and similar calculations making use of modern theories of Stark broadening have also been published by van Regemorter (**80**) and by Cayrel and Traving (**81**). The importance of mutual shielding of positive and negative charges in producing deviations from a Holtsmark distribution is emphasized by Hoffman and Theimer (**82**). Laboratory experiments on collisional broadening have been performed for both Ca I (**83**) and Fe I (**84**).

G. I. Thompson, of the Royal Observatory, Edinburgh, has found that a reformulation of the equations of line formation, which uses temperature rather than optical depth as variable, leads to considerable conceptual simplification of the problem of the profiles of weaker Fraunhofer lines. He has also found that the fact that even moderately strong lines are not saturated, requires that thermally-modified coherent scattering is active.

J. C. Pecker and collaborators have been engaged in a program of study of departures from LTE in the photospheric layers and of their consequences. The evidence for departures was first brought to light during a study of the central intensities of lines of neutral titanium at the center of the solar disk (**85**). Subsequent studies have shown that the effect does not arise from the choice of a model nor from inhomogeneities (**86**). It has also been shown from study of the lines of Ti^+ that the effects of departures from LTE are different for the ionized metals as compared with the neutral metals, in agreement with the ideas of Thomas (**76, 87**). The curves of growth for Ti II suggest a very high turbulent velocity of 4 km/sec (**76**). The departures found from the study of CH lines are compatible with the center-limb variations of the equivalent widths and with the classical rotational temperatures (**88**). The case of iron is in course of study at the Observatory of the University of Istanbul by Messrs Kiral and Hotinli and Mmes Balli, Hotinli and Gökdoğan. Other consequences of departures from LTE are the modification of abundances (**89**), and of the usual theory of weight functions (**90**) and of classical theories of curves of growth (**91, 92**). Additional related topics under investigation at Meudon include the generalization of the Eddington-Barbier relation to cases in which the source function is not a linear function of optical depth (**93**), fundamental problems connected with the formation of line profiles (**94**), radiative transfer in lines for a source function of the Thomas-Jefferies type (M. Dubois-Salmon) and Balmer lines in mustaches (Mlle Sivirine).

A series of papers by Ueno deals with the solution of Milne's problem with noncoherent scattering by the probabilistic (**95**) and Laplace transform methods (**96**) and with the formation of absorption lines in non-coherent scattering (**97**).

The theory of the formation of absorption lines in a magnetic field has been investigated by Stepanov (**98**) and, in a recent paper, he has generalized a formula for the absorption coefficient for mutually orthogonal polarized beams for the case of arbitrary multiplet splitting and derived the corresponding transfer equations (**99**).

Goldberg (**100**) has proposed a method for the empirical determination of line absorption coefficients by intercomparison of the profiles of pairs of lines in multiplets. The method is

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independent of assumptions regarding the atmospheric model and its applicability to both the photosphere and chromosphere has been studied by Unno (**37**).

THE CHROMOSPHERE

In general, the literature on the chromosphere during the past three years reflects the great importance that is now being attached to the dynamic and non-equilibrium character of this layer of the solar atmosphere and to its lack of homogeneity. Together with the corona, the chromosphere radiates strongly at the two extreme ends of the electromagnetic spectrum, and it is already apparent that the newly-found accessibility of these spectral regions, from rockets and satellites and by the techniques of radio astronomy, has greatly accelerated the pace of research on both chromosphere and corona. The picture of the chromosphere and of the events that take place within it is still extremely hazy as far as a quantitative model is concerned. It is hard to avoid the feeling that within the chromosphere there exist one or more physical processes, which have not yet been recognized, and which when discovered will resolve what now appear to be conflicts between different kinds of equally good observational data.

Excitation and Ionization; Line Formation

The structure of the chromosphere cannot be deduced from observations of line and continuous spectra in the absence of an adequate theory of excitation and ionization in an atmosphere in which the deviations from thermodynamic equilibrium are extreme. The fundamental problem is the calculation of the source function and its dependence both upon depth in the atmosphere and on wave-length, given such parameters as the structure of the atmosphere, the intensity of the radiation field, the cross sections for collision, light absorption and scattering, etc. Even when the necessary parameters are known, the required calculations are extraordinarily complex and lengthy; in many cases they can only be guessed at, but even so the sophisticated approach is preferable to those in which a wealth of simplifying assumptions may divorce the calculations from reality.

The depth variation of the source function in non-equilibrium atmospheres of various temperature structures has been studied by Jefferies and Thomas (**1**) with special attention to the influence of a chromosphere on the shapes of spectral lines (**2**). In addition to the role of atmospheric structure, the line profile is strongly affected by the frequency dependence of the source function, which has been studied for resonance lines by Jefferies and White (**3**) and by interlocking effects (**4**). Pottasch and Thomas (**5**) have given a general method for determining the departures from the Saha equation in a hydrogen atmosphere, the main point of which is that high opacity in the Lyman continuum is not sufficient to ensure LTE. Theoretical calculations bearing on the statistical equilibrium of hydrogen and of neutral and ionized helium have been performed in three different papers (**6**), (**7**), and (**8**). Athay (**9**) lays special stress on the relevance of the calculations to the observation of ultra-violet spectra and emphasizes particularly the importance of observations of Lyman-β to the deduction of chromospheric structure. Krat and Sobolev (**10**) have considered the excitation and ionization processes in a non-homogeneous chromosphere; the resulting model is in good agreement with observation. Nikolsky (**11**) has examined the excitation of λ 5694 of Ca XV and of λ 8446 and λ 7774 of O I.

According to Kononovich (**12**) the solar Lyman-α profile is formed in an optically thick layer at a height of 1000 km in the chromosphere. However, an interpretation of the centrally-reversed Lyman-α profile in terms of the Jefferies-Thomas theory (**2**) has led Widing and Morton (**13**) to conclude that the center of the line is formed in a region of the chromosphere in which the electron temperature and electron density have values in the range 55 000°—115 000 °K and $2\times10^9 - 3\times10^{10}/\text{cm}^3$.

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Athay (**14**) reports on a systematic study of the chromospheric spectral lines of Mg I, Ca I and O I, which reveals that the series with metastable lower states are systematically overpopulated with respect to the series with allowed transitions to the ground state. The departures from thermodynamic equilibrium indicated in this way are of the same order of magnitude as those found in hydrogen and helium for energy states of comparable energy relative to the continuum.

A number of attempts has been made to interpret various aspects of the double reversal in the cores of the Fraunhofer H and K lines (**15—20**), but none has been completely successful. It is still not clear as to whether the width of the emission core, which is closely correlated with stellar absolute magnitude (Wilson-Bappu effect), is caused by the Doppler effect (**19, 20**), by the negative temperature gradient in solar and stellar chromospheres (**17, 18**) or by some other process.

Spectrophotometry and Chromospheric Structure

The reduction of data from the February, 1952 eclipse at Khartoum has yielded total intensities and gradients for moderately strong metal lines (**21**) and for weak lines observed in flares (**22**). The observations of Houtgast have been used for the construction of emission curves of growth for Fe I and Ti II, from which densities and excitation temperatures have been derived (**23**). Additional evidence for departures from LTE has come from the analysis of the CN emission from the low chromosphere (**24**). J. Houtgast has measured flash spectra obtained at the 1954 eclipse. The H and K lines show pronounced, very interesting wings which have been studied by Salmang as a function of height. Suemoto and Hiei are measuring line profiles, including very weak lines, observed at the 1958 eclipse employing a combination of the slit and the slitless spectrograph methods. Thompson (**25**) observed a curious bluing of the chromospheric continuum during the 1954 eclipse, which he attributes to Rayleigh scattering in the low-temperature component of the chromosphere. No evidence for Rayleigh scattering is present in Athay's observations (**26**). Numerous flash spectra obtained with high dispersion at the South Pacific eclipse of 1958 have yielded the density distribution of hydrogen atoms based on measurement of the continuous spectrum (**27**).

Hydrogen line profiles in the spectrum of the chromosphere, secured outside of eclipse, have been examined from the point of view as to whether they arise from the scattering of photospheric radiation or whether the lines are re-emitted following the absorption of radiation from the chromospheric surroundings. The shape of the Hβ profile suggests that scattering is predominant (**28**) but other results from the four lines Hα-Hδ indicate that in addition to scattering the field of radiation of the chromosphere itself plays an important role (**29**). Kononovich (**30**) has also carried out a spectrophotometric study of the infra-red chromospheric lines of He I(λ 10 830), H(Pγ and Pδ), Ca II(λ 8542) and O I(λ 7774). The behavior of the infra-red He I line in faculae on the disk has also been studied by Namba (**31**) from photo-electric profiles taken at the Jungfraujoch. Spectrophotometry of the chromosphere and faculae in the H lines and in the H and K lines of Ca$^+$ has been carried out by Khokhlova (**32**).

Many investigations have been devoted to various aspects of the empirical determination of chromospheric structure. In general agreement with eclipse results, the turbulent velocities deduced from the cores of strong Fraunhofer lines show a progressive increase with height (**33**). The same general progression of velocity with height is exhibited by the rms values of the local Doppler shifts in the first four members of the Balmer lines observed on the disk (**34**). Giovanelli reports a new approach to the study of velocity distributions in the chromosphere using a variable wave-length 1/8 Å filter:

'The technique is to take photographs in each wing of an absorption line, and use the method of photographic differencing to reveal local asymmetries in the line. Interpreting the latter as due to Doppler shifts, a photograph is finally obtained whose density indicates the velocity at

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the corresponding place on the Sun. For the general chromospheric structure (but not for plages and filaments), there is an almost 1 : 1 correlation, bright chromospheric regions rising and dark ones falling. This work is continuing intensively.'

Several new models of the solar chromosphere have been published including a model generally resembling Piddington's and based on optical and radio observations of the 1952 eclipse (**35**); a spicular model of the chromosphere derived from radio measurements at millimeter wave-lengths, in which the spicules are both cold and isothermal and in which the temperature variation occurs entirely in the hot interspicular gas (**36**); and a modification of an earlier model derived from 1952 eclipse data to take account of departures from the Saha equation (**37**). Suemoto reports that Moriyama is carrying out a thorough investigation of the current chromospheric models from the standpoint of radio as well as optical observations. Giovanelli draws attention to the possibility of deriving the density and temperature from radio data alone (**38**) as a potentially powerful tool for investigating the transition region between the chromosphere and the corona. This region of the solar atmosphere may also be explored by measuring far ultra-violet emission lines of the solar spectrum (**39, 40**).

Additional information relevant to chromospheric structure has come from rocket observations. Athay (**41**) finds, for example, that the intensity of the He II line at λ 1640 is consistent with chromospheric models derived from 1952 eclipse data. The weak or absent Fraunhofer spectrum noted by Purcell and Tousey below λ 1700 is attributed by Doherty and Menzel (**42**) to absorption by the wings of the Lyman-α line in the high photosphere, which exceeds the absorption of atomic hydrogen and the negative hydrogen ion in the spectral region between the Lyman limit and approximately λ 2000.

Considerable attention has been devoted to studies of the fine structure of the chromosphere and to elucidating the differences in the physical properties of the so-called hot and cold regions. The structure has been studied both on the disk and from accurate profiles of emission lines at the limb. Considerations of numbers, sizes, mean life and Doppler shift leads to the conclusion that the dark mottles seen on Hα filtergrams can be identified with the spicules at the limb (**43**). Athay (**44**) estimates that at a height of 3000 km there are $9{\cdot}3 \times 10^4$ spicules covering 0·6% of the surface. The work of Krat and Pravdjuk (**45**) indicates that the temperatures of the regions of the solar atmosphere in which the He line D_3 appears in absorption on the disk may reach 70 000 °K. Calculations show that these regions can remain in equilibrium with the surrounding undisturbed photosphere only if they possess magnetic fields of about 100 gauss; it is suggested that such regions may be the 'invisible' sunspots observed by Hale. It would seem that this suggestion could be readily subjected to observational test. Kawaguchi (**46**) suggests that the non-appearance of D_3 in most areas of the disk is due to the compensation of absorption of light from the photosphere by emission in the chromosphere. The fine structure of emission in active regions on the Sun has been studied by Shklovsky (**47**) who concludes that their continuous emission is thermal.

Studies of the helium lines in eclipse spectra by different investigators are in general agreement in assigning temperatures in excess of 30 000 °K to the helium-emitting regions (**47–49**). The most recent analysis by Athay and Johnson (**49**) leads to temperature estimates of 40 000°—80 000 °K and suggests that turbulence plays little if any part in accounting for the observed large line widths, which, according to Clube (**50**) imply a turbulent velocity of about 16 km/sec.

Accurate line profiles for the chromospheric spectrum at various heights above the solar limb, obtained outside of eclipse, are helping to delineate the fine structure of the chromosphere. The centrally-reversed character of the emission profiles, first observed by Adams and Burwell in 1915, has now been confirmed (**51–53**). Both Michard (**51**) and Clube (**52**) attribute the emission peaks to the hot spicules and the central absorption to a cooler sur-

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rounding medium, and Michard in particular derives a detailed model from the observations, but such interpretation implies a correspondence between the excitation and electron temperatures which may not in fact exist.

Anomalous broadening of the Ca II K line in the spectra of spicules, as compared with the line broadening observed for Hα, Hβ, Hγ and D_3, has led Athay (**54**) to suggest tentatively that the H and K lines are marked by a non-thermal velocity component of about 20·5 km/sec which may be associated with a spiraling of Ca ions around magnetic lines of force. The possible importance of considering cyclic Doppler shifts from spiraling ions as a source of line broadening in astronomical spectra generally has been emphasized by Platt (**55**).

Energy Balance

The temperature structure of a uniform model chromosphere may be investigated theoretically from the point of view of its stability to changes in energy input. For example, if a rise in temperature results in a decrease of the net emission per gram the atmosphere will be unstable. Following earlier investigations by Parker, and by Athay and Thomas, Zirker (**56**) has studied the problem of the temperature stability of the chromosphere by calculating the net loss of radiative energy as a function of depth in opaque non-equilibrium atmospheres. Temperature plateaus were found in the vicinity of 10 000° and 60 000° for the case of a uniform chromosphere. The calculations are being extended to more realistic non-homogeneous chromospheric models. The temperature distribution in the transition region chromosphere-corona has been calculated by de Jager (**57**) from considerations of the energy balance. Orrall and Zirker are continuing theoretical work on the energy balance of prominences by considering the flow of energy by conduction from the corona into a cylindrical prominence filament. They find that the intensity profile of a filament can be readily explained if the filament lies along magnetic lines of force in a very weak field of the order of 10^{-4} gauss. Dubov (**58**) shows that a balance in the chromosphere can be reached between the energy dissipated by shock waves and the energy carried away by radiation.

Pressure waves arising from the granulation are identified by Watanabe (**59**) with the spicules as a source of heating for the lower chromosphere. Namba (**60**) has calculated the resultant He II emission, on the assumption that hypothetical 'hot streams' containing α-particles may enter the chromosphere from the corona.

THE CORONA

Excitation and Ionization

Both Blaha (**1**) and Schwartz and Zirin (**2**) have recalculated the effective cross section for collisional ionization of Fe XIV by electron impact, finding values substantially lower than earlier ones. According to Schwartz and Zirin, a reduction in the cross section by more than a factor of ten leads to an upward revision of the ionization temperature to 2×10^6 °K, in apparent agreement with values determined from line profiles. Burgess (**3**) points out, however, that cross sections which take account only of *s*-waves and omit contributions from the other orbital angular momentum state of the colliding electron 'are certain to be much too small and should not be used for the calculation of electron temperatures in the solar corona'. Thus, it is suggested that there is still a real discrepancy between coronal temperatures derived from line profiles and from the ionization formula. Elwert (**4**) shows that the usual ionization formula for the corona, in which the rate of collisional ionization is equated to that of photo recombination is to be modified for coronal condensations in which ionizing X-radiation plays a role. In the course of a study of the spectrum of a coronal condensation on eclipse spectra taken by Lyot at the 1952 Khartoum eclipse, C. Pecker (**5**) emphasizes that whereas the calculations of Schwartz and Zirin seem to bring the ionization temperature into agreement with the kinetic

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temperature, they also tend to increase the spread in temperatures demanded by fluctuations in the intensity ratio of the green and red coronal lines. In another contribution (**6**), she points out the importance of considering downward cascades from the level $3s\ 3p^6\ ^2S_{1/2}$ in populating the upper level of the λ 6374 transition.

X-radiation from the corona is generally believed to be concentrated in the form of line rather than continuous emission. It can be shown, however (**7**), that the rocket measurements may be explained as continuous emission at a temperature of $1{\cdot}5 \times 10^6$ °K provided that the corona is highly inhomogeneous, the emitting material being concentrated in 1% of the volume with a corresponding increase in electron density by a factor of one hundred.

Observations of Emission Lines

As usual, a substantial number of papers has reported the results of observations of the red, yellow and green coronal lines made with coronagraphs (**8–15**). Waldmeier (**16**) finds that the general distribution of λ 5694 emissions is similar to that of spot groups, but the emission is more likely to occur over spot groups in higher latitudes than in lower latitudes. In general, the coronal line emission shows a better correspondence with radio emission at twenty-one cm than with spots and plages (**17**). Gnevyshev (**18**) discusses correlations between the intensity of the green line and meter radio wave emission and geomagnetic disturbances. During the course of a statistical study of measurements of coronal line intensities, Trellis (**19**) has been conducting a study of the effects of an east-west asymmetry of the corona and has, at the same time, derived the average properties of coronal jets.

The polarizing filter used by Dollfus since 1957, which isolates four coronal lines, at 5303 Å, 5694 Å, 6374 Å and 6702 Å, and three chromospheric lines, Hα, 5890 Å and 5896 Å, has been modified by the addition of a complementary element which reduces the band pass to 0·48 Å and permits its displacement by as much as 1 Å from the line center. Striking observations have been made of radial velocity effects on the disk and of the appearance of coronal activity as seen in lines of greatly differing ionization potential. Rösch reports the initiation in 1959 of a regular program of photography of the corona in the radiations 5303 and 6374 at the Pic-du-Midi. Measures of intensity of the line 5303 since 1943 will soon be distributed in the form of an atlas containing isophote maps. A good correlation has been established between the Pic-du-Midi measures of coronal line intensities and those of Kislovodsk, Wendelstein, Climax and Sacramento Peak. It is hoped that the present provisional intensity scale may be transformed to an absolute scale. Minnaert (**20**) has studied the corona spectrum photographed by him at the 1954 eclipse, which coincided with an exceptional minimum of solar activity. The total emission amounted to $0{\cdot}4 \times 10^{-6}$ of the solar emission and the outer corona was slightly redder than the inner corona. The equivalent width of the green line was only 2 Å, about one-tenth of the normal value.

Wlérick reports the following developments in connection with the observation of the infrared coronal lines and with the construction of an emission-line coronameter:

'En collaboration avec Jean Pierre Dumont j'ai étudie les raies d'émission infra-rouge de la couronne solaire avec le coronographe et le spectrographe de l'Observatoire du Pic-du-Midi. Avec des poses photographiques de 2 à 4 heures sur des plaques kodak I – Z, et une fente radiale nous avons obtenus en Juillet 1960 de beaux spectres montrant les raies coronales 10 747 et 10 798 Å du Fe XIII jusqu'à des distances du bord solaire variant suivant les cas entre 8 et 12 minutes d'arc. Nous pensons que l'étude de ces spectres permettra une meilleure détermination due gradient d'intensité des raies coronales.

'Pierre Charvin construit actuellement un coronométre pour la détection photométrique de la raie verte suivant le principe indiqué par Lyot en 1950 et suivant les recommandations de

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l'Union Astronomique Internationale. La partie électronique d'un tel instrument doit être d'excellente qualité et Pierre Charvin apporte un soin particulier à sa réalisation. Il pense avoir l'appareil en fonctionnement avant l'Assemblée de Berkeley.'

Observations in White Light; Coronal Condensations

The extraordinarily sensitive polarimeter developed by Dollfus (**21**) is being employed for the mapping of the solar corona in white light without a coronagraph. Installation of the polarimeter on the coronagraph at the Pic-du-Midi permits the observation of jets to distances of up to 35′ from the limb (**22**).

Photometry of the polar rays of the solar corona at the time of the 1952, 1954 and 1955 eclipses have revealed that the electron density is about five times that of the surrounding space in the corona (**23**). From the form of the polar rays at the 1954 and 1955 eclipses, Shimooda (**24**) finds that the Sun's polar field is like neither that of a dipole nor of a magnet but resembles that of a so-called 'force-free' magnetic field. Measurement of the long equatorial streamers photographed at the South Vietnam eclipse of 1955 enabled Saito (**25**) to draw conclusions as to the variations in electron density and velocity between the Sun and the Earth's distance.

Mlle Debarbat and Pecker (**26**) have carried out a systematic study of data from radio electric eclipses of the Sun with a view to establishing the properties of active zones of the corona. The results are very compatible with those currently given by interferometric methods. Observations of occultations of the Crab nebula by the solar corona continue to add new knowledge regarding coronal condensations and the Sun's magnetic field. Analysis of observations made in June, 1958 by Hogböm (**27**) reveals the scattering to be highly anisotropic, which is interpreted to be caused by irregularities aligned in the general magnetic field. The direction of the field was found to be approximately radial between ten—thirty solar radii. A model of a coronal condensation has been derived by Hiei (**28**) from eclipse spectrograms. The electron density is found to be about ten times that of the normal surrounding regions and the temperature is about 4×10^6 °K. A similar model of a coronal condensation has been derived by Kawabata (**29**) based entirely on radio observations. Newkirk (**29a**) supports the view that the long-lived coronal condensations are at temperatures of around 2×10^6 °K. A different view of coronal condensations is taken by Tamburini and Thiessen (30), who argue that the coronal condensations may not have the high temperatures generally attributed to them but may even have temperatures lower than that of the neighboring corona. Unsöld (**31**) emphasizes the importance of the ray structure and inhomogeneity of the corona in theoretical treatments of its structure.

Structure and Models

A rediscussion of the contributions by the K and F components of the corona by Waldmeier (**32**) shows how the spectroscopic and polarimetric determinations can be harmonized. Three new models of the corona are of special interest. Panovkin (**33**) obtained a model of the inner corona based on radio data which shows a temperature maximum of 3×10^6 °K between solar radii 1·1 and 1·3. Newkirk (**34**) has developed a number of models of the corona for the use of radio astronomers from observations over the quiet disk, and over polar and active regions, which were secured with the High Altitude Observatory K-coronameter developed by Wlérick and Axtell. A more recent analysis (**29a**) has led to a new model of coronal densities somewhat higher than in previous models and to a new interpretation of the slowly varying component of the twenty-one cm radio noise flux. The equation of hydrostatic equilibrium has been reapplied by Pottasch (**35**) to the determination of the temperature distribution of the corona to a distance of twenty solar radii. The temperature distribution shows a maximum value of $1{\cdot}4 \times 10^6$ °K between 1·1 and 3 solar radii.

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Billings (36) has determined the gradient of kinetic temperature in the corona from the analysis of line profiles obtained over extended regions on the solar limb from 0–100 000 km. The distribution of matter density with temperatures deduced from line profiles has also been studied (37), and evidence has been found of systematically higher kinetic temperatures associated with λ 5303 emission as compared with λ 6374 (38). According to Billings (39) the distribution of λ 5303 half widths in a coronal region shows an oscillatory pattern which may arise from a transverse hydromagnetic wave. The propagation of electro-magnetic waves in the corona over a sunspot with a strong magnetic field has been studied by Ginzburg and Zhelezniakov (40).

SUNSPOTS AND PROMINENCES

Extensive references to sunspot and prominence investigations will be found in the report of Commission 10. Those cited below have been communicated by members of this Commission and are included at the risk of some duplication.

A number of researches on sunspots are in progress at the Göttingen Observatory including a study by Stumpff of the wave-length dependence of the intensity ratio of sunspot umbra to photosphere between 4100 Å and 8600 Å, a curve of growth analysis of the equivalent widths of a large number of metallic lines in sunspots by Elsässer, an investigation of the wings of rather strong magnesium and iron lines in an effort to improve the pressure model for sunspots by van 't Veer and a study by Bauer of the width of the nitrogen line λ 4912, which has no Zeeman splitting, and which yields turbulent velocities in the photosphere and umbra of 1·8 and 2·1 km/sec, respectively.

The curves of growth for sunspots and the neighboring photosphere have been compared by Zwaan (1) and by Zeldina and Zemanek (2). According to Kornilov (3) the magnetic field of the sunspot has no influence on the equivalent widths and the curve of growth. Von Klüber reports that Miss J. M. Cox has begun a program to determine the line profiles of the Zeeman components on selected lines in the magnetic fields of sunspots from observations with the solar spectrograph of the Cambridge Observatories.

Jefferies and Orrall (4), in a continuation of their study of physical conditions in prominences, confirmed their finding that the hydrogen and helium lines are probably not radiated from the same volumes, and that the line-width determinations of temperature are very unreliable. The ratio of Balmer continuum to the free-free and scatter continuum at longer wave-lengths appears to be very much more reliable, particularly in setting an upper limit to temperatures. Observations of this ratio in a number of prominences give temperatures ranging from 10 000 °K in quiet region prominences to 22 000 °K in very active rapidly changing prominences. Thermal and turbulent velocities have been derived from the profiles of hydrogen, helium and Ca^+ lines in quiescent prominences by ten Bruggencate and Elste (5). Tandberg-Hanssen (6) has published an extensive and detailed investigation of temperature conditions in prominences including a special study of the excitation of helium.

INSTRUMENTS

A number of references to new instruments and techniques for solar observation have been given in the preceding sections, while others will be reported in the *Draft Report* of Commission 9.

Two new spectrographs for solar research have been constructed at the Paris Observatory and installed at the Pic du Midi (1). They are a solar spectrograph of nine meters focal length and a special spectrograph designed to record the spectra of flares.

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Labs reports the development and construction at Heidelberg of a grating-double monochromator instrument, with a resolving power $\Delta\lambda/\lambda = 60\,000$ in the first order, which permits the measurement of the energy in absolute units in sharply defined regions of the solar spectrum from 3000 to 12000 Å. Attempts at measurement with this instrument in 1959 at Teneriffe in the Canary Islands and in 1960 at Heidelberg, were thwarted by unfavorable weather conditions, but the measurements will be repeated during the summer of 1961 at the Jungfraujoch or at the Pic-du-Midi.

The Dominion Observatory in Ottawa is constructing a magnetograph designed primarily for the study of the magnetic field distribution in active solar regions. The instrument, which will be completed in early 1961, will incorporate automatic compensation for Doppler shifts, including the accurate measurement of line displacements over the disk as a by-product.

A new type of solar telescope has been built for the Göttingen Observatory by Cox, Hargreaves and Thomson (London) using a design of ten Bruggencate (**2**). The instrument, which will be located 300 m above the Lago Maggiore near Locarno, consists of an equatorially mounted primary paraboloid 240 cm in focal length with a Gregory coudé enlarging system 1 : 10.

New instrumental developments at the Pulkovo Observatory include an interference-polarizing filter for the K-line with 0·5 Å band pass, constructed at the Institute of Crystallography of the U.S.S.R. Academy (**3**), a solar magnetograph with automatic compensation of radial velocities (**4**), a static spectroheliograph for observations of the solar disk with bandwidths of 0·08 Å and 0·26 Å (**5**), and various items of instrumentation for the observation of coronal lines at a southern station near Kislovodsk (**6**).

From the Sternberg Astronomical Institute, Sitnik (**7**) has described the solar horizontal telescope of the Astrophysical Observatory at Kuchino, which is equipped with a spectrograph-monochromator and photo-electric devices for recording of spectra with the help of an electronic oscillograph. Sitnik (**8**) has also discussed various aspects of the problem of absolute photometry and spectrophotometry. A new type of coronagraph has been constructed (**9**) for the high altitude station of the Sternberg Institute near Alma-Ata (height 3050 m).

A new spectrograph employing an echelle grating has been installed at the Crimean Astrophysical Observatory (**10**) and used to obtain simultaneous spectra of flares in a large region of the spectrum from the red to the ultra-violet. Banin (**11**) has described the equipment of the Solar Observational Station in Ussury.

Plans for the design and construction of rocket- and satellite-borne solar instrumentation, which are being undertaken in a number of countries, were described at the tenth Astrophysical Colloquium at Liège in July, 1960 and are published in the *Proceedings*.

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