12. RADIATION AND STRUCTURE OF THE SOLAR ATMOSPHERE
(RADIATION ET STRUCTURE DE L'ATMOSPHÈRE SOLAIRE)

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INTRODUCTION

By action of the Executive Committee of IAU, the report for 1970 is restricted to half the length of the 1967 draft report; the bibliography and the abstracting of work already published are essentially eliminated. The report is no longer to serve primarily as a review of accomplishments between General Assemblies but rather as a report of work in progress. These changes were adopted by the Executive Committee in order to reduce the cost of publishing the reports.

Several commission members have voiced the opinion that the extensive bibliographies in past reports have been the most valuable contributions of the reports and they have objected to the elimination of the bibliography. Also, material from some observatories and from some national groups that have been submitted for inclusion in this draft report have contained only abstracts of work already published. The rules adopted by the Executive Committee do not permit the report to abstract published works except in evaluating general progress in solar astronomy. We express our regret to these commission members and to these institutions that we have not been able to include the abstracts and bibliography in the present report.

In preparing the present report, we have been forced to ask the obvious question, *"What function should the report serve?"* If it is not to contain a bibliography, its use is restricted effectively to the current General Assembly and perhaps the following year. Although the report may have some historical value, it obviously will not serve as a useful reference document for research purposes. What, then, is the function of the report? We have assumed for the present report that its purpose is to inform those engaged in research in solar physics of what is happening in solar physics in 1970. It is not obvious that this is the correct assumption to make, and we urge commission members to communicate their whishes with respect to the report to the commission officers.

If the reports continue in the future to serve primarily as a report of work in progress at the time of the General Assembly, it will be mandatory that more commission members contribute to the report. Requests for information for the current draft report received very limited response. As a result, we are not able to provide a well balanced report. A further consequence of a report that does not extensively survey the literature is that it will reflect inevitably the personality and interest of the person preparing the report and will tend to be more editorial in character. This adds to the need for each commission member to submit appropriate material for future reports.

Strong contributions to this report were made by L. Delbouille, M. N. Gnevyshev, R. G. Giovanelli, C. de Jager, M. Kopecký, G. Newkirk, A. K. Pierce, G. Righini, M. Rigutti, Z. Suemoto and M. Waldmeier. The final report was prepared by R. G. Athay, although most of the coronal section was taken verbatim from a report by G. Newkirk.

INSTRUMENT DEVELOPMENT

Instrumentation in solar astronomy is undergoing relatively rapid growth. Major new telescopes are under construction, new observatories are being established and new instrumental techniques are being developed.

The new 45 m tower telescope at Meudon is producing a good solar image and spectroscopic observations will begin during 1970.

The large new tower telescope at the Sacramento Peak Observatory is producing good images also, and will soon be ready for spectroscopic work. This instrument contains several new features including a rotatable telescope floating in a mercury bath. The tower extends 41·5 m above ground and sits over a pit approximately 60 m deep. The entire telescope and spectrograph assembly are evacuated. A turret mirror system of 76 cm aperture at the top of the tower feeds a primary mirror of 55 m focal length to produce a 51 cm solar image.

New horizontal telescopes include the Meudon 40 cm telescope with 20 m focal length and the Kiev 44 cm telescope with 17 m focal length. The latter telescope is operated by the Astronomical Observatory of the Ukrainian Academy of Sciences.

Coronagraph systems with 53 cm aperture designed for large angular and spectral resolution have been installed at Kislovodsk, Abastumani and Alma-Ata. Companion instruments are being prepared for installation at the Crimean Observatory and at Debrecen (Hungary).

We draw attention to the successful operation of the OSO VI satellite carrying an improved spectrometer capable of both spectral scanning at a fixed point on the sun and raster scanning fixed areas at a given wavelength. The raster scan mode of operation produces spectroheliograms of areas measuring approximately 7 arc min on a side with a time resolution of 30 sec or of areas measuring 46 arc min on a side with a time resolution of 8 min. The spectrometer covers the wavelength band 280–1360 Å and has a spatial resolution of approximately 35 arc sec.

We draw attention also to the development of successful X-ray telescopes that are producing high angular resolution solar X-ray images of excellent quality, and to the development of a zone-plate X-ray camera at Utrecht.

Narrow band filters utilizing two etalon Fabry-Pérot filters in series (Kononovich, Sternberg) or one or two etalon Fabry-Pérot filters in combination with multilayer dielectric filters (Goldberg, Harvard) are being successfully developed and tested. Tests indicate that the filters are stable if controlled to $\pm 0{\cdot}5\,^{\circ}$C and may give pass bands as narrow as 1/20 Å.

A particularly interesting experimental program is the stellar atmosphere simulator being developed at the Max-Planck Institut für Extraterrestriche Physik (Specht, Garching). This device will heat a H-He plasma to 3500–7000° and will permit the controlled introduction of other elements.

A Josephson-Junction detector capable of very fast time response and high sensitivity in mm and far infrared regions of the spectrum has been used successfully by Ulrich (University of Texas). Development of the detector and its application to solar astronomy are continuing.

THE CONTINUUM SPECTRUM

Renewed interest in the continuum spectrum of the sun has been stimulated by a desire to find more accurately the location and value of the temperature minimum and to determine the temperature structure in the low chromosphere and upper photosphere. Most of this effort is directed towards observations in the far infrared and submillimeter regions of the spectrum. Parallel, but less intensive, efforts are directed toward obtaining more accurate data in the far ultraviolet.

Present data indicate that the temperature minimum region is observed at wavelengths of about λ1650 and at about 300μ, or greater. The exact location in the submillimeter region is difficult to determine from existing data and is still quite uncertain. At present, the submillimeter data of Eddy, Léna and MacQueen of the High Altitude Observatory and far ultraviolet data of Parkinson and Reeves of Harvard College Observatory each suggest that the minimum temperature is near 4400°. There are uncertainties in both sets of data, however, and more work remains to be done in determining reliable absolute intensities in these regions of the spectrum.

New infrared observations are in progress at Institute d'Astrophysique in Paris in the 0.3 to 30μ band (Peyturaux), at Observatoire de Paris in Meudon in the 10–1000μ band (Gay and Léna), in Switzerland in the 15–1000μ band (Müller, Geneva, Knubuhl and Stettler, Zurich), at the Jungfraujoch in the 1·2–12μ band (Delbouille and Roland), in Liege (spectral band unknown,

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Zander, Delbouille and Roland), and at High Altitude Observatory in Boulder, in the 300–1000 μ band (Eddy, MacQueen and Mankin).

New observations of the ultraviolet continuum in the $\lambda\lambda$1400–1875 band are planned at Harvard (Parkinson and Reeves) and in the $\lambda\lambda$1800–3000 band at Verrires (Bonnet). These were the only ultraviolet continuum observing programs reported to the author. It is both somewhat surprising and regrettable that more effort is not being made in this important spectral region.

In the violet end of the photographic spectrum we are still plagued by uncertainties in the location of the continuum and by uncertainties in opacities. Houtgast and Namba (Utrecht) have attempted to locate the continuum more accurately between $\lambda\lambda$2988 and 4087. A number of workers report difficulty in fitting the violet continuum with theoretical models. Thus, additional opacity is required from $\lambda\lambda$1800–5000 by Heintze (Utrecht), for $\lambda < 5000$ by Sitnik (Sternberg) and $\lambda < 2000$ by Nishi (Japan). It is not clear at this time, however, just how much of the difficulty is due to unknown opacity sources and how much is due to either uncertainty in the continuum location or faulty model atmospheres.

The Lyman continuum observations from OSO IV and the newer data from OSO VI obtained by the Harvard group are highly valuable contributions for studying middle and upper chromospheric structure. Similar experiments in the far ultraviolet with improved spectral resolution could provide much badly needed information about the structure of the low chromosphere and upper photosphere.

There is still some dispute over the spectral distribution of energy observed at the center of the solar disk. The results of Labs and Neckel differ somewhat from those of Peyturaux, for example. Again, it seems more work is needed and we particularly need confirming results from different investigators.

THE LINE SPECTRUM

A number of factors are contributing to the current high level of interest in the line spectrum. These include: the opening of new spectral regions in the infrared and far ultraviolet, interest in the high photosphere and temperature minimum region, interest in improved chromospheric models, contradictory results on abundances (notably iron), the study of mass motions and their influences on line profiles, and the advent of improved techniques for treating non-LTE problems in line formation. The new tower telescopes with high resolution spectrographs at Meudon and Sacramento Peak Observatories will undoubtedly spur even greater interest in the line spectrum. Also, the high resolution vacuum telescope at the Jungfraujoch has been automated to obtain high resolution, low noise spectra.

The comprehensive *Second Revision of Rowland's Preliminary Table of Solar Spectrum Wavelengths* by Charlotte M. Sitterly, M. G. J. Minnaert and J. Houtgast (National Bureau of Standards Monograph, 61) represents another milestone in solar astronomy. Mrs Sitterly reports that section 4 of *The Analyses of Optical Atomic Spectra*, National Bureau of Standards Publication 306 was scheduled for publication in September 1969. Earlier sections were published in 1968 and 1969. Mrs Sitterly is currently preparing a revised table of ionization potentials together with the ionization limits for each spectrum and the energy levels of the terms measured from the ground configuration. The work has already been completed for atoms H through Cl.

Precision wavelength measurements of lines in the interval $\lambda\lambda$2900–10000 using interferometric wavelengths of Thorium lines as standards are being made by Brault, Brechinridge and Pierce (Kitt Peak Observatory). They report that a large number of previously unidentified faint solar lines have been identified with CN by using new CN laboratory spectra in the red and violet.

Identification of many faint lines in sunspot spectra with the molecules NiH, H_2O and O_2 has been reported by Wöhl (Göttingen). He further reports that lines of MgH are broadened by magnetic splitting and not by blending as supposed by some authors.

High resolution photoelectric scans of the spectrum in the range $\lambda\lambda$3000–3600 by Mohler and Mitchell (Michigan) have added many new lines, with equivalent widths, relocated wavelengths and suggested identifications. This work is currently being extended to λ2900. A similar atlas extending from $\lambda\lambda$3000–8000 is in preparation by Delbouille and coworkers at the Jungfraujoch .

Tables of wavelengths and identifications of the lines measured in the *Photometric Atlas of the Solar Spectrum from λλ7498–12016* (Delbouille and Roland) are in press.

Roddier (Nice) is developing an atomic beam spectrograph to obtain precision profiles of the Sr I 4607 and Ca I 4227 lines. It is planned to make the instrument light enough for balloon work as well as for use on refracting telescopes.

Observations of line profiles and precise wavelength measurements in the far ultraviolet and infrared spectral regions remain as two of the major unexplored observational problems in solar physics. New work is beginning in these directions, however. We note especially the observations of the profiles of lines of O I and C II by workers at the Laboratory of Atmospheric and Space Physics (Boulder) and the observations of Mg II and Lyman α profiles by the Verrieres group. Both groups plan to extend their observations to other lines in the near future.

ROTATION

The solar oblateness reported by Dicke (Princeton) together with the lingering problems of differential rotation are sustaining a relatively strong interest in solar rotation problems. Theoretical work on solar rotation is being carried out in Boulder independently by Nakagawa, Durney, Benton and Gilman, in Tübingen by Unz and Walter and in London by Roxburgh.

The observation that the angular velocity of the lower solar atmosphere varies with height (Livingston, Kitt Peak) raises the question as to whether a similar phenomenon exists in the solar corona. An examination of the rotation of coronal condensations during the period 1964 to 1967 (Hansen, Hansen and Loomis, HAO Hawaii) demonstrates that the rotation rate varies from year to year and in any given year may be different between the two hemispheres. At lower latitudes, the rate appears to agree with that determined from filaments and sunspots while at high latitudes the rate appears to be similar to that of filaments, which is over 2° per day faster than that displayed by polar faculae. These data show a dependence of angular velocity with height which appears to depend upon both latitude and the phase of the solar cycle. Both increasing and decreasing angular velocity with height appear. The details of this phenomenon are poorly understood. There is some indication that the high latitude coronal features are being influenced by the more rapidly moving magnetic centers at lower latitude.

A question of continued interest is that of the co-rotation of the corona and loss of angular momentum of the solar wind. Theoretical investigations have demonstrated that the magnetic field of the sun imposes effective co-rotation out to approximately 15 $R_\odot$. These models predict an azimuthal velocity of the solar wind at 1 AU of approximately 1 km s^{-1}, which is considerably lower than the approximately 10 km per second observed (Brandt, Goddard; Hundhausen, Los Alamos). These models predict, moreover, that even within 15 $R_\odot$ no strict, rigid rotation of the corona can be expected and that there should be a very slight spiraling of coronal structures toward the east. Empirical corroboration of these theoretical results appears impossible at the present time. Although rocket observations of the outer corona (Koomen, Seal, Purcell and Tousey, U.S. Naval Research Laboratory) show that streamers out to 10 $R_\odot$ appear straight, any realistic solar wind model would produce such a result even in the absence of a torque produced by the solar magnetic field.

A calculation by Weber (Kitt Peak) suggests that the angular velocity of *ions* in the corona may increase with height in special circumstances in closed magnetic loops. No empirical evidence for such a surprising phenomenon has been obtained.

Radar observations of the corona (James, El Campo) have produced detailed measures on macroscopic motions in the corona. This appears to be the only direct measurement of the solar wind, which has an average velocity of approximately 20 km s^{-1} at a distance of 1·5 $R_\odot$. Echoes also appear with velocities of up to 200 km s^{-2}. The lack of angular resolution in the radar observations makes their interpretation difficult so that it is presently largely a matter of speculation as to which echoes correspond to large blobs of moving coronal material and which may represent shock waves.

THE PHOTOSPHERE

The studies of phenomena related to super granules, of magnetic fields, and of mass motions in the photosphere currently play strong roles in photospheric physics. Further interest has been added through efforts to determine more accurately the location and value of the temperature minimum, and through recent controversies over the solar abundance of iron. The Bilderberg conference on the photosphere has added extra stimulus and has provided a trial model through which we can bring our different studies to a common standard of reference. As a result of these stimuli interest in the solar photosphere stands, perhaps, at a higher level than ever before.

A. *Granules, super-granules and their systematic motions*

Rösch and his coworkers at Pic du Midi are continuing their study of the evolution and structure of granules using cinematography. Some of the Pic du Midi observations together with cinematographic observations of granules made at Sacramento Peak are being studied by P. Mein and his coworkers at Meudon. Additional observations are planned with the new Meudon tower. Léna successfully observed granule structure in the infrared region of the spectrum at Kitt Peak and is planning to continue granule studies in the infrared. M. Rossbach (Göttingen) is studying sizes and lifetimes of granules near sunspots on high resolution photographs obtained by Beckers and Schroter at Sacramento Peak. Namba and coworkers (Utrecht) are studying granulation structure from stratoscope I photographs obtained at Princeton. They find large granules which darken in the center and divide into smaller cells giving the appearance of several granules each of shorter lifetimes than the lifetime of the large granule and its fragments. They are studying also velocity shifts and line profiles in granule spectra of the C I $\lambda 5052$ line obtained at Sacramento Peak Observatory.

Edmonds (University of Texas) reports that a statistical study of granule data by the Tukey fast-Fourier-transform method leads to power and coherence spectra that differ significantly from results obtained from the same data with the mean-lag-product method. The Tukey method is capable of higher resolution and is less sensitive to finite data sampling and smoothing.

Edmonds further reports that continuum brightness fluctuations (granules) have wavelengths concentrated near 1200 km whereas low frequency radial velocity oscillations have wavelengths concentrated near 4000 km. He concludes, therefore, that the two phenomena are distinct. The new results come from bi-dimensional power spectra.

H. Reiling (Göttingen) is studying the relationship between line asymmetry and intensity fluctuations using spectra obtained by Livingston at Kitt Peak. The objective of this study is to obtain a better idea of the true velocity of unresolved elements in granules and intergranular spaces.

V. A. Krat and Ch. Abusametov (Pulkovo) report that the average velocities of features in the photosphere decrease as the size of the element decreases.

From one dimensional scans obtained with the velocity servo of a magnetograph, Tanenbaum, Wilcox, Frazier and Howard (Mt. Wilson) have analyzed velocity fields for the five-minute oscillations and for the flow in super granules. The oscillating elements of average size less than 6000 km appear to be randomly distributed but can statistically combine into a large oscillating area. In the photosphere they find that the brightness fluctuation leads the velocity by less than 90° and conclude that traveling waves are present at this level. In the low chromosphere the phase lead is 90° and they conclude that standing waves are present.

The super granule flow has a diameter of about 10000 km, an amplitude of 100 m/s and a lifetime of over 3 h.

R. Howard and A. Bhatnagar report that they have obtained an excellent granulation spectrum which they are analyzing to obtain physical characteristics of granular and intergranular spaces.

A. Title (Harvard) is analyzing right and left circular polarized pairs of two-dimensional arrays of spectra. Regions one arc min square are scanned and spectra are obtained in each polarization at 0·5 arc sec intervals. Each spectrum is a 2Å band centered at $\lambda 5250$. The arrays provide information on the magnetic field, velocity field, intensity field or any other property of the spectra desired.

Observers measuring velocity fields should be cautioned by the theoretical profiles computed by Beckers and more recently by Athay that when velocity gradients are present in the region of line formation standard techniques for measuring velocities may give completely erroneous results.

B. *Magnetic fields*

Large scale mapping of the solar magnetic field continues to be carried out at Mt. Wilson, Kitt Peak and Sacramento Peak Observatories and at the Crimean Observatory. The new solar observatory at Aerospace Corporation (Los Angeles) is using Leighton's photographic subtraction technique with the 24″ vacuum telescope and spectrograph to study the fine structure of the magnetic field.

Title (Harvard) reports that one of the more interesting features of his pairs of polarized two-dimensional spectra (see granules and super granules) are the very large field gradients near sunspots, up to 2500 G/arc sec at the umbral boundary and up to 1500 G/arc sec at the outer penumbral boundary.

Frazier (Aerospace Corporation) has found a high correlation between longitudinal magnetic field strength and the presence of downward velocities.

Perhaps the most remarkable new discovery in solar magnetism is that the sun observed as a star by Severny (Crimea) has a net magnetic field that varies roughly periodically with half the solar rotation period and that the sign of the residual solar field correlates with the sign of the interplanetary magnetic field (Severny, Wilcox and Colburn).

Staude (Heinrich-Hertz Institute) and Rachkovsky (Crimea) are studying the effect of magnetic field inhomogeneities on line profiles and the reverse problem of inferring magnetic fields from line profiles when unresolved inhomogeneities are present. Again, observers should make note that when gradients are present either in the magnetic field or in velocity standard techniques may give incorrect magnetic field strengths.

Krat (Pulkovo) reports that "magnetic knots" are small pores of approximately 0·3 to 0·4 arc sec in size and are located at the boundaries between radial velocities of opposite sign.

C. *Chemical composition and microturbulence*

Photoelectric scanning of the spectrum with double pass spectrometers can yield precision profiles of Fraunhofer lines. As line profiles become more reliable there is a turning from the curve of growth method of abundance analysis to profile representation or spectrum synthesis. One should now insist that profiles as well as equivalent widths should be explained. For those elements for which only a few lines are observable, often badly blended, profile fitting (spectrum synthesis) is the only method acceptable. For others it is a major improvement in analytical technique, utilizing more data and capable of yielding correspondingly more information.

Still further information may be extracted from the lines by using center-limb data. One often finds that an adequate explanation of line profiles and equivalent widths at disk center is no longer adequate for the same lines observed near the limb. Similarly, an adequate explanation for lines of a given range of excitation potentials may fail when the range of excitation potentials is expanded. Some authors are finding that when many lines are studied or when lines are studied at different disk positions the chemical abundance deduced for an element depends upon excitation potential or upon position on the solar disk. Such results may be indicative of poor *f*-values, of non-LTE effects or of poor models for the photosphere. We can never have great confidence in abundances, however, until all such difficulties are either eliminated or properly explained.

Aside from problems with *f*-values (line spectrum), the outstanding difficulties in properly explaining the lines and obtaining proper abundances are in the effects of non-LTE and mass motions. It is clear that non-LTE effects are present in many line profiles and that the microturbulence is not homogeneous. We are still in need of analytical techniques that allow adequately for these effects. These are difficult problems, to be sure, but it is time to face them.

Studies of microturbulence in photospheric molecular lines are reported by Sitnik (Sternberg).

Studies using precision profiles are reported as being carried out by the following workers or by groups associated with them: Aller (UCLA), Altrock (Sacramento Peak), Gurtovenko *et al.* (Kiev), de Jager (Utrecht), Jefferies (Hawaii), Müller (Geneva), Pecker (Paris, Nice), White (High Altitude Observatory) and J.-P. Swings (Liege). Much of the observational work for such studies has been obtained at Kitt Peak, Sacramento Peak and Jungfraujoch Observatories in collaboration with personnel at these observatories.

New Fe I *f*-values recently obtained by such workers as Garz and Kock (Kiel) and by King and collaborators (California Institute of Technology) have cast serious doubt on the reliability of the Fe I *f*-values published in recent years by the U.S. National Bureau of Standards. This is both an encouraging and disturbing development; encouraging because of the new interest in the problem, the new techniques developed, and the promise of better data in the future; disturbing because of the suspicion it casts on other *f*-values as well. Goldberg calls attention to the fact that although the new Fe I *f*-values give a photospheric iron abundance that agrees with that obtained from [Fe II] lines the new abundance disagrees by an order of magnitude with the abundance obtained from Fe II lines by Warner. Thus, we still have a discrepancy and we still must hold *f*-values as suspect.

D. *Models*

The Bilderberg continuum model has served usefully as a reference model, whether used as a working model or as a target for criticism. It seems, at this time, to be most deficient at $\tau_c > 1$ where it gives temperatures that are too low and at $\tau_c < 10^{-2}$ where the model was uncertain from the beginning. A revised model is in preparation by Gingerich (Harvard).

The author believes that the usefulness of the Bilderberg model as a reference model owes its success in large measure to the fact that many people contributed to the discussion leading to the model and that they, and their colleagues, therefore felt some allegiance to it. Had the same model been produced by one person there seems little doubt that it would have received much less attention than has been accorded the Bilderberg model. It seems in the best interest of solar physics, therefore, that the Bilderberg model be revised by a process similar to that which gave birth to it.

Recent ultraviolet data obtained by Parkinson and Reeves (Harvard) and infrared data obtained by Eddy, Léna and MacQueen (High Altitude Observatory) indicate that the minimum temperature in the upper photosphere is near 4400°. Both the infrared opacity and the ultraviolet opacity (Cuny, Paris) indicate that $T_{\min}$ occurs near $\tau_5 = 10^{-4}$. The proper evaluation and location of $T_{\min}$ is of crucial importance for comparison with theoretical models and for evaluating the mechanical energy flux required to sustain the observed temperature distribution.

Feutrier (Meudon), Jordon (Goddard) and Thomas and Gebbie (Joint Institute for Laboratory Astrophysics, Boulder) have studied the rise in temperature at small optical depths resulting from the Cayrel mechanism. All of these studies suggest that the rise in temperature in the low chromosphere or upper photosphere is largely due to the Cayrel mechanism rather than mechanical energy dissipation. However, they find temperatures in excess of 4600°, particularly when $\tau_5 \leqslant 10^{-3}$.

The only known mechanism for cooling the external layers of the photosphere below 4600° is line blanketing. Athay (High Altitude Observatory) has computed a model photosphere using non-LTE blanketing but omitting the Cayrel mechanism. He finds a radiative equilibrium temperature of $4340° \pm 150$ at $\tau_5 = 10^{-4}$. The surface cooling effect increases rapidly if the surface temperature is raised and would strongly resist a warming tendency by the Cayrel mechanism.

Studies of strong Fraunhofer lines with the intent of determining the solar model more accurately in the region of $T_{\min}$ and the low chromosphere are being carried out at a number of places. Some of the groups involved in this work are listed in the preceding section on the discussion of profile fitting. Others include Avrett (Harvard), Athay and Skumanich (HAO, Boulder), Johnson (Indiana),

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Kostik and Orlova (Kiev), Linsky (JILA, Boulder), Mugglestone (Queensland), Sitnik (Sternberg), Suemoto (Japan), Cuny and Dumont (Paris), and Tanaka (Japan).

New techniques for handling non-LTE line transfer problems in inhomogeneous atmospheres and in moving atmospheres are being studied by Hummer (JILA, Boulder), Jones (Goddard), Kalkofen and Rybicki (Harvard), Skumanich and House (HAO, Boulder) and Wilson (Sydney).

THE CHROMOSPHERE

It is no longer possible to distinguish sharply between some chromospheric and photospheric studies. A single strong Fraunhofer line may be formed in regions extending from the low photosphere to the middle chromosphere. The continuum spectrum also has been extended into spectral regions where the emission is chromospheric.

The temperature minimum region is a phenomenon of both the photosphere and the chromosphere, and the current lively interest in this region is unifying much of the photospheric and chromospheric research. Similarly the current emphasis on the interpretation of the profiles of strong Fraunhofer lines is unifying research in these two areas. Accordingly much of the discussion in the section of this report dealing with the photosphere pertains to the chromosphere as well.

The generally accepted belief that the mechanical energy heating the chromosphere and corona passes through the photosphere further unites photospheric and chromospheric research. There is widespread interest in the nature of the mechanical energy. How much is required? How does it propagate? Where and how is it dissipated? These questions are both "photospheric" and "chromospheric" and should not be divided by an artificial line such as the solar limb. It appears that much of the recent effort in chromospheric research has been "dissipated" in the region of temperature minimum.

A. *Eclipse spectra*

The tabulation of line intensities observed at the 1962 eclipse by Dunn *et al.* (*Ap. J. Suppl.*, 1968) represents a valuable and long awaited addition to the literature. Other reports of spectra from the 1962 and 1966 eclipses already published or to be published soon come from Hurokawa *et al.* (Japan, 1962 eclipse), Hiei and Hirayama (Japan, 1966 eclipse) and the Utrecht group (1966 eclipse). The 1966 data obtained by Hiei and Hirayama have sufficient spectral resolution to provide very good line profiles and represent an especially valuable contribution.

Plans to observe the chromosphere at the March 7, 1970 eclipse include groups from the Kwasan and Utrecht Observatories.

B. *Models*

Analysis of continuum data for the low chromosphere from the 1966 eclipse is being continued by Gebbie and Thomas (JILA). Linsky (JILA) and Gingerich, Noyes and Avrett (Harvard) are combining studies of the ultraviolet, infrared, radio and visual continuum in an effort to obtain a better model of the low and middle chromosphere.

Analyses of Lyman continuum data obtained with OSO IV and OSO VI are continuing by Noyes and Kalkofen (Harvard).

Although considerable effort has been devoted to chromospheric models in the past three years there is little to report in the way of real progress. The chromospheric part of the Bilderberg model was largely a step backward since it ignored well established eclipse data giving electron densities both in the chromosphere and corona. Much of the model evolution since the Bilderberg model has tended to re-emphasize the electron density models and to restructure temperature models to fit the various other data as well as possible. It has been known for many years that eclipse data give an electron density at 500 km above the limb of approximately 2×10^{11} cm^{-3} and a neutral hydrogen density of approximately 10^{14} cm^{-3} (cf. Henze, *Solar Phys.*, 1969, **9**, 65). The only known source for such a high electron density is hydrogen ionization and there seems no way to avoid the conclusion that the temperature is high enough to produce a fractional ionization of hydrogen of about 0·1 %. This requires a temperature near 5700° if proper allowance is made for non-LTE effects. In any case, it seems clear that the temperature at 500 km above the limb is some 1000° to 1500° above the temperature at the solar minimum.

The eclipse values of hydrogen and electron densities at 500 km lead to an optical depth at this height of $\tau_5 \approx 10^{-5}$. Recent trends to set $T_{\min} \approx 4300$ and to place it near $\tau_5 \approx 10^{-4}$ require that the temperature gradient between $\tau_5 \approx 10^{-4}$ and $\tau_5 \approx 10^{-5}$ be large. This feature was absent from the Bilderberg model.

A second obvious defect of the Bilderberg model is that at very small τ_5 it gives densities that are below coronal densities. The only way proposed thus far (Athay, HAO) for avoiding this difficulty is to markedly reduce the thickness of the low temperature regions of the chromosphere and to require a second steep rise in temperature in the general range of 1000 to 2000 km above the limb. Newer models are tending in this direction (Noyes and Kalkofen, Harvard; Avrett and Linsky, Harvard and JILA).

There is no doubt that the chromosphere has lateral structure of significance and that single component models must finally give way to multicomponent models. As a point of departure for such multicomponent models, however, it is important that we establish the best possible single component model.

Some of the studies of line data in progress have been mentioned in the photospheric discussion. Efforts to properly explain the K_2 emission phenomena are still in progress. The trend here seems to be in the direction of favoring the interpretation based on an effectively thick chromosphere, which is not inconsistent with the trend in models of the low chromosphere. Some authors (e.g. Tanaka, Japan) still favor the effectively thin interpretation, however.

Tandberg-Hanssen and Smythe (HAO) are studying the excitation of resonance doublets in the chromospheric spectrum. They report that observed doublet ratios in Ba II of 2·5 and greater can be accounted for if interterm collision rates are sufficiently small.

Efforts to obtain better chromospheric models during the past few years have concentrated on the low chromosphere and the chromosphere-corona transition region. New attempts are being made to arrive at a better understanding of the middle chromosphere, however. Avrett (Harvard) and Poland (HAO) are studying helium excitation using both XUV and eclipse data. Studies of the hydrogen Lyman lines (Athay, HAO) and of the C II lines (Berger, LASP, Boulder) are in progress. Athay and Canfield (HAO) find from their study of the profile of the λ1304 O I line in the XUV that a microturbulent velocity of 7–8 km/s is needed in the middle chromosphere. Existing chromospheric models give the correct line flux, but they give too much self-reversal in the center of the line.

Pecker (Paris) calls attention to the need in chromospheric research for coordinated studies incorporating radio, IR, XUV and visual data, both continuum and lines. Too often, in the past, models have been based upon overly restricted data, only to be replaced by other models based upon equally restricted data.

C. *Structure and spicules*

Although we have accumulated considerable data on the nature of the structure observed in different spectral lines, we have made little progress in relating the structure in one line to that in another, and we have made even less progress towards relating the structure observed in the lines to physical structure in the chromosphere. These are difficult problems, of course, and we cannot expect that a given structure will produce the same changes in brightness or have even the same size in two different lines even though the different lines may be formed at the same height. The problem is further compounded by the ambiguities introduced by Doppler shifts and, in some cases, magnetic splitting.

Bray and Loughhead (Sydney) are continuing their high resolution studies. Loughhead has suggested that spicules are seen as dark mottles on the disk. He identifies the bright mottles with bright features seen above the limb, but reports that these features are distinct from spicules.

Spicule studies at the limb are being continued at Pic du Midi and at eclipse by Mouradian (Paris) and at Kislovodsk by Nikolsky and Sazanov. The latter find that the line-of-sight velocity can change sign for a given spicule and may reach 20 km/s. Similar results were reported by Pasachoff, Noyes and Beckers using data from Sacramento Peak.

Pasachoff (Harvard) notes in his study of the emission structure observed in the K line that:
(1) The emission is often confined to one side of the line, usually the violet side.
(2) The maximum intensity of the violet peak exceeds that of the red.
(3) The $\Delta\lambda$ positions of K_2 show an rms deviation of 0·04 Å.
(4) K_3 tends to be displaced from line center away from the most intense K_2 emission.
(5) The structure of K_2 emission is not necessarily related to continuum threads. Suemoto (Japan) is conducting a similar study of the K line disk structures.

Studies of oscillatory motions in the chromosphere are reported by Orrall (Hawaii) and by Zhugzhda (ITMIP, Moscow).

D. *Chromosphere-corona transition region and chromospheric heating*

Far ultraviolet emission line data obtained from satellites and rockets have made it possible to study the chromosphere-corona transition region in some detail. A conference on the transition region was held in Boulder in August, 1969, with about 40 participants. A limited number of the proceedings of this conference are still available. They can be obtained on request by writing the High Altitude Observatory, Boulder.

New data from the Harvard experiment on OSO VI and from rocket experiments at Culham are being used by those groups to obtain improved models of the transition region and new information about transition region phenomena.

The problems of heating the chromosphere and of the energy mechanisms in the chromosphere-corona transition region are being studied by a number of authors including Delache (Nice), Dubov (Crimea), Kopp (HAO), Kuperus (Utrecht), Mäckle (Tübingen), Moore (Stanford), Stein (Brandeis) and Ulmschneider (Heidelberg). Although there are still major questions to be resolved, it appears that heating by shock waves is adequate. The magnetic field structure and the period of the waves are known to play important roles in the propagation and dissipation of the waves. Exactly how to take these phenomena into account in constructing models is not well understood, however. The energy dissipated by shocks must be disposed of mainly by radiation in the chromosphere and by radiation, conduction and mass motion in the transition region. The radiation losses and mass motions are difficult to take into account properly and are still limiting the usefulness of such models. Much improvement is being made, however, and we can confidently expect significant improvement in the theoretical models in the near future.

E. *Abundances*

Pecker and Pottasch have developed a method for obtaining relative abundances in the chromosphere that avoids, in some cases, major uncertainties from non-LTE effects. The method combines the use of central intensities of disk lines with the total intensities of lines observed at eclipse and is applied wherever possible to transitions from the ground state. Abundances derived using this technique show better agreement with coronal and meteoritic abundances than with classical photospheric abundances. This is particularly true of the iron abundance, which agrees with the newer photospheric values from Fe I and Fe II and with the coronal abundances from forbidden lines.

THE CORONA

A. *The coronal density structure*

Continued observation of the corona has confirmed the validity of the *form* of the classical

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coronal density models. However, all observations point to the fact that the previous sunspot maximum (1957–1958) and minimum (1962) were characterized by electron densities about twice those of the Van de Hulst models for corresponding periods of solar activity. A detailed documentation of the variation of coronal electron densities from 1964 through 1967 has recently been published by Hansen, Hansen, Garcia and Loomis (HAO, Hawaii).

The density structure of the corona has often been treated as a spherically symmetric component with the superposition of one or more streamers. Researchers now have at their disposal several new models to describe "typical" coronal streamers as well as ellipsoidal distributions attempting to reproduce the dependence of density upon longitude in an average corona.

One aspect of the density structure of the corona which requires considerable attention in the future is that of the fine scale structure. It is now clear that such structure extends from the upper chromosphere out into the chromosphere-corona transition region (Withbroe, Harvard) and into the corona (James, El Campo). The scale of these fluctuations in the corona varies from the 3×10^4 km which some authors (Newkirk and Harvey, HAO, Boulder; Ivanchuk, Kiev) identify with the supergranulation down to the few hundred kilometers which are responsible for interplanetary scintillation. The origin of such fluctuations is largely unknown.

Looking to the future, we can hope for the resolution of several problems concerning the density structure of the corona. Synoptic observations of the outer corona are going to be an essential observation in order to be able to determine the true three-dimensional distribution of material. The relation of such structures as streamers and rays to solar surface features is also presently largely unknown. Even less is understood about the evolution of such structures although there is some indication that streamers endure for several solar rotations (Bohlin, Mt. Wilson). Even in the area of the gross, global structure of the corona much remains to be done. Many of the present models employ convenient but unproved assumptions about the symmetry of the corona along the line-of-sight. Clearly, a systematic investigation of the uniqueness of the density models used to fit the observations is required.

Observations of the white light corona from ground stations are being continued by Hansen (HAO, Hawaii) and by Dollfus (Meudon). Eclipse observations (1970) are planned by Saito and Hata (Japan). Balloon observations are in progress at Meudon (Dollfus).

The Apollo 11 astronauts obtained several photographs of the *F*-corona, which are yielding useful results on brightness near the sun (Kovar, Manned Spacecraft Center, Houston). A white light coronagraph is being prepared for flight on a future Apollo mission by Newkirk (HAO, Boulder).

B. *Heating and temperature of the solar corona*

The problem of explaining the high temperature of the solar corona has received considerable attention in the past several years. Most of the theories have been concerned with the details of the generation of mechanical energy in the lower solar atmosphere and the deposition of this energy by shock waves in the chromosphere and corona. Recently the role of ion acoustic waves, which dissipate their energy by Landau damping in the lower corona, has been pointed out by d'Angelo (European Space Research Institute, Rome). Perhaps, the most important aspect of these theoretical investigations has been their demonstration of the fact that the magnetic field in the lower atmosphere can be expected to play a very large role in determining the rate of energy deposition in the corona as well as the structure of the chromosphere-corona transition region (Kopp and Kuperus, HAO and Utrecht and Mäckle, Tübingen). As mentioned in the section on coronal condensations, there now appears to be substantial evidence (Noyes, Withbroe and Kirshner, Harvard) that the energy deposition into the corona is, in fact, increased substantially above active regions.

Little progress has been made in gathering empirical information which adds measurably to our knowledge of the temperature structure of the corona with a view to distinguishing between competing theories of coronal heating. The classical measurements of coronal line widths generally have insufficient spectroscopic resolution for a definitive measure of the profile and are often confused by macroscopic motions in the corona (Delone and Makarova, Sternberg). The identification of new coronal lines (Edlén, Lund; Wagner, Sacramento Peak) of Ni XI and Fe IX suggests that even the quiet corona contains a temperature fine structure.

About the only empirical evidence bearing on the problem of coronal heating is that obtained by solar radar echoes (James, El Campo) at a radar frequency of 38 MHz, which is reflected at approximately 1·5 $R_\odot$, where some echoes are found moving with a velocity of approximately 150 km s^{-1}. If these echoes are identified as the reflection off shock waves moving through the corona, the slowing down of these waves at approximately 1·6 $R_\odot$ can be interpreted (Brandt, Goddard) as delineating the extent of coronal heating out to 1·6 $R_\odot$. Since the radar observations do not have any appreciable angular resolution and the exact location and amplitude of the disturbances are unknown, it is impossible at this time to judge whether such waves are truly sufficient to account for the required energy flux in the corona. Another piece of information favoring the heating of the corona over a substantial depth comes from the measurement of the relation between the velocity and temperature of protons in the interplanetary medium (Burlaga and Ogilvie, Goddard). The present solar wind models can adequately account for the quiet period temperature and velocities but appear to require the hypothesis of an extended region of coronal heating near the sun to account for the higher range of temperature and velocity which is observed during disturbed periods.

Spacecraft observations have also provided (Hundhausen, Gilbert and Bame, Los Alamos; Kozlovsky, Israel) the first direct evidence for the high temperature of the corona. The presence of ions of O IV to O VII in the solar wind at 1 AU demonstrates that even though the local temperature of the wind is quite low (the most probable temperature is $4{\cdot}8 \times 10^4$ K while the average temperature is $1{\cdot}4 \times 10^5$ K), the state of ionization is effectively frozen into the solar wind rather low in the corona. The O VII to O VI ratio implies that the ionization is fixed at a level where the temperature is approximately $2{\cdot}8 \times 10^6$ K. During periods of activity in the solar wind the ion ratios imply a temperature of approximately 3×10^6 K suggesting that small, hot coronal condensations may, in fact, have a large contribution to the solar wind. The observation of He I in the solar wind has been suggested as evidence for the presence of a cold, perhaps subsonic component, to the wind; however, it appears likely that charge exchange in the neighborhood of the earth can equally well account for the observed abundance of singly ionized He (Hundhausen, Los Alamos).

X-ray and XUV spectrograms and spectroheliograms of the corona also, in principal, provide the basis for improved information on both the density and temperature structure of the corona. A number of groups are now involved in X-ray and XUV programs. These include: Michard (Meudon), Dijkstra (Utrecht), Blake (Chicago), Vaiana (American Science and Engineering), Goldberg *et al.* (Harvard), Peterson (University of California, San Diego), Neupert (Goddard), Friedman (U.S. Naval Research Laboratory), Teske (Michigan), Pounds (Leicester), Burton *et al.* (Culham) and groups in the U.S.S.R.

A number of researchers report new theoretical work on collision cross-sections, *f*-values and ionization equilibria for coronal ions. Van Rensbergen (Holland) is studying the influence of excited levels and of autoionization and dielectronic recombination on the equilibrium of coronal ions. Studies of collision cross-sections and *f*-values are reported by Blaha (Goddard), Lexa (Czechoslovakia) and Belý (Nice).

Coronal magnetic fields

In spite of the fact that the determination of magnetic fields in the corona is extremely difficult, the question of such fields and their influence on the solar corona has been one of tremendous activity in the past several years. Although, in principal, capable of yielding information on these fields the measurement of coronal emission line polarization (Eddy and Malville, HAO, Boulder; Hyder, Mauter and Shutt, Sacramento Peak; Nikolsky and Sazanov, Abastumani) have proved difficult to interpret in terms of the magnetic field in any detailed manner. Other researchers reporting studies of coronal line polarization are Charvin (Pic du Midi), Delone and Makarova (Sternberg) and Nikolsky and Tetruashvili (Abastumani).

Faraday rotation of artificial and natural radio sources (Levy *et al.*, Jet Propulsion Laboratory, Pasadena) is also a potentially useful tool although no quantitative measurements of the coronal field have yet been determined. The Razin effect in solar radio emission (Boischot and Clavelier, Paris; Ramaty and Lingenfelter, Goddard; Bohlin and Simon, California Institute of Technology) appears to have given us the most unambiguous determination of the field at a value of 0·3 to 0·5 G at $2R_{\odot}$ above an active region. All these researches refer to the observation of a single Type IV burst and similar observations of other events is urgently required.

The connection of coronal magnetic fields to the density structure of the corona has been attacked from two directions. In the first, the surface distribution of the fields over the entire sun is used to calculate the fields in the corona; the shapes of the field lines are then compared to the visual appearance of the corona (Newkirk, Altschuler and Harvey, HAO, Boulder; Schatten, University of California). Although there is always some question about the validity of such current-free calculations in the corona, the correspondence between the shapes of the field lines and the small scale density structures in the corona such as arches and rays suggests that much of the small scale structure is due to the filling of magnetic tubes by various amounts of coronal material. These same analyses suggest that coronal streamers, indeed, form over extended regions of opposite polarity on the surface of the sun. Such a picture makes the apparent association of streamers with filaments a quite natural consequence. A similar conclusion was reached by Sturrock and Smith (Stanford) but without the benefit of a quantitative model of the coronal magnetic fields.

A second approach to the role played by magnetic fields in forming coronal streamers has involved the detailed solution of the hydromagnetic equations for the solar wind with a simple distribution of magnetic fields on the surface of the sun (Pneuman and Kopp, HAO, Boulder). These models predict rather well the shape of the streamers, and the density distribution within and outside of a streamer. The calculations may be extended to 1 AU where it is found that the streamer represents a small increase in the local density and velocity over the background corona.

The question of the extension of the corona and its magnetic fields out into the interplanetary medium has also received considerable attention. Although it is found that a correlation exists between the fields calculated for the corona at 1·6 $R_{\odot}$ and those at 1 AU (Schatten, Wilcox and Ness, University of California and Goddard) there still exists considerable disagreement as to whether the "mapping" or the "nozzle" hypothesis is a better interpretation of the data. At the present time, the connection between such visible structures in the corona as streamers and the features seen in the particles and fields at 1 AU is largely unknown.

R. G. ATHAY
Vice-President of the Commission

WORKING GROUP ON CENTRAL LINE INTENSITIES

Of a select list of about 40 Fraunhofer lines distributed between λλ3083–7122, central intensities corrected for scattered light, ghosts and instrumental profile, has been obtained for 18 lines. Uncorrected values of central intensity for a number of other lines are available. A complete list of the results of all observers will be given at the General Assembly in Brighton.

A. KEITH PIERCE
Chairman of the Working Group

WORKING GROUP ON SOLAR ECLIPSES

The working Group on Solar Eclipses regrets Dr J. Houtgast's resignation as Chairman of the Group. However, Dr Houtgast will maintain his membership and continue to give his experience to the group.

The total eclipse of September 22, 1968 was actively observed by many groups in spite of its short duration. Reports on the observations are expected to be given during the 1970 IAU General Assembly.

A great deal of work has been done everywhere in view of the total eclipse of March 7, 1970.