10. COMMISSION DE L'ACTIVITE SOLAIRE

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INTRODUCTION AND GENERAL REMARKS

Although the period under consideration, covering the years 1961–63, is characterized by a considerable decay of solar activity, the research activity in the field of Commission 10 was on a level even higher than in preceding years. The large amount of observational data accumulated during the years of the IGY-IGC presented a broad base for various researches. The publication of Daily Maps of the Sun by the Fraunhofer Institut, the Bulletin on Solar Data U.S.S.R. (Solnechnye Dannye), the Bulletin of Solar Phenomena (Tokyo), and of some other bulletins of solar activity have been continued on a regular basis.

The system of solar patrol has been operating regularly in most of the observatories and stations which started this work during the IGY.

The present Report is based mainly on the separate reports compiled by members of the Organizing Committee. The contributions made by Dr Z. Svestka (spectra of flares), Dr W. O. Roberts (flare-associated phenomena and prominences), the late Professor M. A. Ellison, (direct observations of flares), Professor R. Michard (flares and sunspots), Professor K. Kiepenheuer (flocculae and disturbed chromosphere) have been extremely valuable in the compilation of the present Report. Problems which are more closely connected with the quiet Sun, as well as those concerning solar activity, as studied at solar eclipses, and solar-terrestrial relations, have not been included in this Report. The investigations of solar radio-emission relating to solar flares are included with flare-associated phenomena. The Report is strictly confined to investigations which have been published or communicated since January 1961.

As in the preceding one, the present period is characterized by considerable progress in observational work and in the technique of solar research. The observations of X-ray and $L\alpha$ activity of the Sun, made with the aid of satellites and rockets, deserve to be specially mentioned. New possibilities are offered also by balloon telescopes such as Stratoscope I. Photoelectric techniques of observation of solar magnetic fields have also been considerably improved and extended to the observations of transverse magnetic fields. Although the main observational material discussed in the papers below relates to the preceding years of enhanced solar activity, a set of new important observations was obtained, relating especially to sunspots and their magnetic fields. New important observations of radio-bursts associated with the active

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Sun were made. As regards general concepts underlying the processes that we observe in active regions, the period considered may be characterized as that in which, from one side, many efforts were concentrated on making more precise and clear the most important features of known processes and, from the other side, a necessary reconsideration of some concepts has arisen. This is probably best shown, for instance, in respect of the present state of our knowledge about sunspots. New confirmations of the importance of the fine structure of active regions and of the role of magnetic fields in the processes observed in these regions have been obtained. But, nevertheless, we are not able at the present time to combine all the pieces of our knowledge about active regions into a coherent pattern, and a lot of further research work should be done. This conclusion is one which follows from two recent important symposia: one on 'The Solar Spectrum', at Utrecht (August 1963), and the other on 'Stellar and Solar Magnetic Fields' at Rottach-Eggern (September 1963).

The progress of research in radio-frequency observations of solar phenomena has been remarkable during the period since the last IAU meeting. In particular, the observations of flare-associated radio-noise bursts of Type IV have expanded, and the spectral, polarization, and directional characteristics of this radio emission have received great attention. Much of this research comes under the purview of Commission 40 (Radio Astronomy), and is reported there. Increased attention has been given to shock and acoustic waves in the plasma comprising the solar corona, to genesis and acceleration of the 'solar wind' and solar corpuscular streams in the corona, and to the extension of these coronal phenomena far into interplanetary space. Needless to say, this work has been aided by artificial satellites and space probes.

Many years of planning have, at last, culminated in the preparation of a nearly continuous H-alpha cinematic record of the solar disk, co-operatively produced to cover the period 1959 July 6–20. Copies of the film have been supplied to the co-operating observatories, and are available for general distribution from the IGY World Data Centres for solar activity. The film was produced under the guidance of the Working Committee.

The appearance of some good books relating to solar physics should be noted; these are *Physics of the Solar Chromosphere* by R. N. Thomas and R. G. Athay (Interscience Publ., N.Y., 1961) and *Solar Flares* by H. J. Smith and E. v. P. Smith (Macmillan Co., N.Y., 1963).

The following are the requests and suggestions to be considered.

G. Moreton recommends, particularly during the quiet years of solar activity, that a fast-circulation 'newsletter' be disseminated among solar observers. The newsletter should mention special observations, should request exchanges of data on specific events, and should summarise unusual phenomena that have been noted. A successful analogue of the newsletter has been circulated for solar radio observers by A. Fokker. Moreton suggests it might be incorporated into the *HAO Preliminary Report of Solar Activity* now circulated weekly.

G. Moreton calls attention to the fact that narrow-band multi-layer interference filters have improved measurably in recent years, to the point where they have great interest for solar work, He uses a two-inch diameter filter at H-alpha, which has a half-peak bandwidth under 8 Å. and a 50 per cent transmission. Such filters can be produced at a small fraction of the cost of bi-refringent filters.

Flare patrol and solar patrol (including white light) is now being handled as if it were required only for geophysics. For solar research, according to K. O. Kiepenheuer's proposal, much higher image resolution, good image quality during 24 hours and concentration of the patrol of specially active regions are needed. Special weight should be given also to white-light patrol of the full disk. For fine-grain film or plates the minimum of the disk diameter on the negative should be at least 15 cm, in order to bring out at least two seconds of arc.

Flare importance ratings based primarily on area lose significance and reliability near the solar limb. A. Giesecke (Instituto Geofisico del Peru) urges adoption of a new convention that

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considers line broadening, intensity, or other accompanying phenomena for flares at or near the limb.

The flash phase of a flare often occurs at a distinct time between flare start and flare maximum. G. Moreton notes that the flash time correlates better with solar X-ray bursts and with type III and centimetric wavelength radio bursts. He urges flare cinematography at a rate not slower than one picture per ten seconds during high activity, and urges specific notation for publication of the time of the flash phase.

R. N. Bracewell has called attention to the fact that observations with a one-dimensional resolution of 50 seconds of arc are possible at 9cm, and can resolve sources having opposite circular polarizations within active regions. He urges the development of fast-acting microwave instruments for high-resolution flare patrol, reaching down to five seconds of arc. Co-operative international patrols with such equipment would have great advantages.

J. Kleczek has suggested that a special study should be made of the regions of eruptive prominences where H-alpha emission disappears as the prominence rises. Coronal spectra, K-coronameter records and radio-heliograms, he suggests, should be concentrated on such phenomena during the eruption and for some time thereafter.

O. Mohler calls attention to the extremely challenging problem of using Lyot-type coronographs to improve the observational study of corona-prominence relationships involving K-corona, emission corona and prominence intensity and motions. The importance of improved optical observations, conducted simultaneously with radio observations, is vastly enhanced, W. O. Roberts points out, by the space research vehicles and the manned space explorations that will be deployed at the next solar maximum.

Improvements in surge classification conventions have been recommended by Y. Öhman. He suggests additional symbols to indicate, for limb surges, brilliance as well as length. Another, he suggests, should be added for width. He also calls for more attention to bright and dark surges on the disk.

The astrophysical laboratory of the Bucarest Observatory possesses registration plates microphotometers (Lirefo 2) and other instruments and, like many astrophysical laboratories, urges that the exchange between the observatories of spectrograms and other observational materials be extended. The Commission has suffered great losses: during the period considered such prominent scientists as Dr R. McMath and Professor M. A. Ellison have died. Solar physics is indebted to Dr McMath for many ingenious inventions in the techniques of solar research (moving-picture processes, a new type of solar tower telescope, new techniques in infra-red, vacuum spectrographs of high dispersion and other extremely valuable contributions). One of the most active investigators of the Sun, Professor Ellison was one of the pioneers of systematic and comprehensive exploration of solar activity and especially of solar flares and their influence on the Earth. A set of most valuable contributions in this field will always be connected with the name of Professor Ellison. During the same period, Professor M. S. Eigenson, whose name is connected with a set of interesting investigations of the complex relations between the Sun and our atmosphere, also died.

In conclusion I wish to express my gratitude to Dr N. Stepanyan for help in the preparation of this Report, and to Dr Mattig for his contribution-review on sunspots which was used in compiling the final text.

A. EQUIPMENT

The new solar tower of the Osservatorio Astronomico di Roma at Monte Mario is now fitted with spectroscopic equipment including a 250mm grating with 300 lines/mm, blazed for the 11th order (63°) with a resolving power of 825 000.

Externally-occulted coronographs of small aperture have been developed for balloon,

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satellite and rocket vehicles. Such coronographs can now be realized with instrumental background light only slightly different from a total solar eclipse. The external occulter, coupled with the use of apodization through a notched occulting disk (**1**) or multiple occulting disks (**2**) leads to great improvement in background relative to a conventional Lyot coronograph. Instrumental stray light can be reduced to below 10^{-9} of the mean solar disk, thus leading to an expectation of observing the corona to a height six or more solar radii if balloon or space vehicles are used to carry them above the atmospheric scatterers. Wavelength ranges inaccessible from Earth can also be used. Flights with such instruments have already been conducted (**3, 4**).

A coronograph for spectral observations of monochromatic coronal emissions at sea-level, at times other than during eclipses has been realized at Nizmir (Institute for Earth magnetism and propagation of radio waves, near Moscow) (**5**). A K-coronameter at Kislovodsk Mountain Station has been tested (**6**).

A monochromator, with double reflection from gratings reducing completely the scattered light, has been realized and tested (**7**). The new construction of the spectro-heliograph at the Kislovodsk mountain station is described in (**8**). A spectrophotometer for rapid photo-electric records of the solar spectrum is described in (**9**). The methods of investigation of the solar magnetic field received further development in (**10–16**). In (**10**), a modification of the usual Babcock photo-electric method for registration of longitudinal magnetic fields is achieved, at the Crimean solar tower, in such a way as to permit to record transverse fields, as well as longitudinal fields using the magnetic sensitive line. The application of this method to the various measurements of polarization on the solar disk, and an analysis of possible instrumental effects of polarization on the measurements of magnetic fields are given (**11**). A further improvement in the method of recording transverse fields, permitting to reduce several times the time-resolving power, has been recently described in (**12**). At Nizmir (near Moscow) the scheme of solar magnetograph with a single slit and photo-multiplier set in the magnetic sensitive line is adopted for the simultaneous measurements of transverse and longitudinal components by means of Stokes' parameters of polarized light (**13**). An essentially different method of the determination of transverse magnetic fields, based on polarization measurements in a broad spectral region as determined by the pass-band of the glass-filter, was developed at Meudon Observatory by the aid of a polarimeter with an objective of diameter 10 cm and focal length 4 m (**14**). A new model of a solar magnetograph for the measurement of the longitudinal field with a single-slit photometer and automatic regulation of sensitivity has been made at Pulkovo Observatory (**15**). A new solar magnetograph for measurements of longitudinal fields was constructed and put into operation at the Fraunhofer Institut (**16**).

Magnetic-fields patrol using a device similar to Deslandres' 'spectro-enregistreur des vitesses' is achieved at Meudon Observatory with the aid of a mirror telescope of 40 cm aperture and 25 m focal length. The grating spectrograph of 7 m (focal length) uses a 1200 lines/mm grating in the 2-nd order, the dispersion being 3·85 mm/Å (**17**).

A printing device permitting maps of solar magnetic fields to be obtained in the form of field-strength printed on a sheet of paper is described in (**18**). Interesting new uses of Savart interferometers have been developed for use on limb prominences (**19**).

Two new Hα-heliographs for the flare patrol are being put into use in Meudon. The first provides for successive exposures of disk and limb on the same flare as first introduced in Sydney. The other will take in rapid succession three pictures with different pass-bands.

A promising new technique of three-colour moving-picture photography of Hα-chromosphere, at different positions of the pass-band (0, ±0·5Å), has been recently developed (**20**).

A great advance in the technique of solar research was the successful use of Stratoscope-I for direct photography of solar surface and especially of sunspots at high resolving power, permitting to reveal fine structure and subtle changes in active regions on the Sun (**21**).

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B. SUNSPOTS

1. *Statistics and general picture.* In studying activity near sunspot minima, Giovanelli has found that the separate curves for the frequencies of appearance of new groups in the decaying and rising cycles are very reproducible. The main differences between various minima are in the phases of onset of the new cycles. Fluctuations about the curves appear to follow a Poisson distribution. Fitted to data for the current cycle, these results have formed the basis for predictions of activity during the present sunspot minima (**1**).

The present course of the 80-year solar cycle points to a weak maximum of the next 11-year outburst of solar activity (**2**). An analysis of the last three 80-year solar cycles yields the following gradual variation of the behaviour of the 11-year outbursts of solar activity: the maxima, on the average, became higher, the minima became deeper, and the asymmetry of the spot curve increased (**3**, **4**).

The butterfly diagram of the frequency of sunspot group formation has been compared in (**5**) with that of the average importance of sunspot groups. Considerable differences have been found. In (**5**) the existence of the secondary high-latitude zone of sunspots is also argued. The evidence for an 80-year period of sunspot activity is considered in (**6**). The mathematical error in the derivation of the Spörer law by Babcock is considered in (**7**), and it is shown that the correct derivation, based on Babcock's concept of a 22-year cycle, can explain the shift of high-latitude active regions (prominences and corona) towards the poles. The result of a statistical investigation of the relation between areas and classes of sunspots is: in a diagram plotting heliographic latitude against time the regions of higher mean sunspot area coincide with regions of higher concentration of sunspots of classes E and F (**8**). In a statistical investigation of the magnetic polarity of sunspot groups in the vicinity of the Sun's equator it is shown that in a few cases sunspots have the 'wrong' polarity as a result of a migration from one hemisphere to the other (**9**). Analytical relations have been found which represent with satisfactory approximation the variation of some indices: (*a*) the relative sunspot number, (*b*) the areas of sunspots, umbrae and faculae, (*c*) the average life-time of the sunspot groups, and (*d*) the number of sunspot groups originating during each synodic rotation of the Sun; each index within each sunspot cycle and from cycle to cycle, is represented as a function of the corresponding time of rise and certain periodic terms (**10–15**). Latitudes of the spot groups at the beginning of the 19th solar cycle was not so high as to explain the exceptionally high relative number at the maximum of that cycle, and the mean areas of the spots (total areas/relative numbers) was not smaller as in other cycles. Nor was the empirical formula of Xanthakis fulfilled in this cycle (**16**).

The correlation between the zone-width of sunspot occurrence and the relative number was confirmed (**17**). Proper motions of H- and I-type spots have been studied (**18**), and also the latitude drift of short-lived sunspots (**19**). In (**20**) and (**21**), anomalous separation and fusion of spots have been described. The change in the ratio of the areas of umbra to penumbra during the cycle was discussed (**22**), and also the development of the area in connection with local magnetic fields (**23**). For short-lived spots, a secular variation of the area—magnetic field-relation has been found (**24**). Using photometric methods the visibility and the east-west asymmetry has been examined (**25**). Special attention to the peak in the intensity plot of the coronal emission line against heliographic latitude was paid in (**84**). It was found that the limb-passage of a spot group almost always accompanies a peak or peak-range. The life of a peak-range varies from one limb-passage to five or more successive limb-passages. The mean latitude of the peak-range has a tendency to be higher than that of the associated spot group and usually varies irregularly by 5 or 10 degrees during successive limb-passages.

Observations of the Wilson-effect provide the result that the spots are more transparent than the photosphere, and that we can assume a funnel model for sunspots (**26**). A new sunspot

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classification is proposed, the spots evolution is taken into account and new statistical relations have been derived (**27**). Highly-resolved stratoscope pictures offered the possibility of studying the fine structure elements in the penumbra (**28**). The spots surrounding granulation show smaller elements than the granulation outside active regions (**29**). The difference in the dimension of the granules inside sunspots and in the photosphere is attributed to the influence of the sunspot magnetic field (**30**). Detailed photometric maps have been made of the intensity distribution within two large sunspots. These maps have confirmed the existence in spot umbrae of small, extra-dark region ('cores') located not at the centre of the umbra but near one end. On the basis of the maps, a new model of the magnetic field configuration inside a sunspot umbra has been proposed in (**31**), incorporating the hypothesis that the umbral core represents the region of greatest field strength. There has also been analysed a sequence of photographs showing the births of some small sunspot pores. The growth of the spots was accompanied by disturbances in the intervening photospheric granulation, which lasted for about three hours. They are interpreted as evidence of the existence of a rising loop of magnetic flux between the spots (**32**).

About one hundred spot photographs among ten thousand photographs, obtained during the period from 1958 to 1961, were studied. The main results are that almost all umbrae have a faint (usually a granular) structure and that the shapes of these umbral granules are different from those of the photospheric ones. Frequently the umbral granules are arranged in beads or chains, usually connected with the projected parts of the penumbral fine structure. The bridges grow out of these beads or chains (**85**).

2. *Magnetic fields of sunspots.* The appearance of the transverse component of the magnetic field in the spectra of the umbrae of some sunspots, observed by means of a Hale-Nicolson plate, has been analyzed with the aid of Seares formula permitting to determine the angle of inclination of the lines of force to the solar surface. The appearance of a triplet pattern for the lines with normal Zeeman effect is attributed to a special form of magnetic field where the lines of force are horizontal rings in the deep layers, and in higher layers are spirals with pitch increasing with height (**33, 34**).

Line profiles of magnetically-split lines, calculated by means of the Unno theory, are compared with observed profiles for three sunspots (**35**). This comparison shows that the lines of force in the penumbra are horizontal almost everywhere. The Unno theory was also used in (**35**) to determine the orientation and strength of magnetic fields in a bipolar group. Consideration of several hundred profiles of λ6302 over the group near the centre of the disk showed that the angle between the magnetic field and the line of sight never exceeds 30° inside the umbra, in contradiction with the results of (**33, 34**). The general agreement of observed and calculated profiles was less good than expected (**36**). The same angle was determined as 30° in (**37**).

The first magnetographic determinations of transverse magnetic field pointed to the existence of vortex structure of this field in the penumbra and around some sunspots (**38, 39**). The analysis of maps of transverse fields, together with the usual maps of longitudinal fields for a large sunspot-group (1961 September 2–September 8) showed this vortex structure persisting for several days. The mean strength of the transverse fields outside spots is 2–3 times—and inside spots is 1·6–1·7 times—larger than the strength of the longitudinal fields. The general configuration of a magnetic field inside a spot is similar to a force-free field (**40**). Further examination of the combined maps of transverse and longitudinal fields for many sunspot groups showed that: (*a*) between spots, this field can approximately be considered as due to separate dipoles-sunspots; (*b*) the vortex structure of transverse fields is rather an exception than a rule; (*c*) inside sunspots the field can deviate largely from the classical Hale picture showing sometimes small inclusions of pure transverse field or even more complex patterns; (*d*) the orientation of the transverse field changes very rapidly with depth, as well as along the

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surface, in the regions and inside of sunspots; (*e*) some spots show almost synchronous variation of the magnetic flux and of the curvature of the vortex spirals, if a vortex exists, (**41, 42**). The structure of transverse fields around sunspots follows very closely the Hα-chromospheric structure (**43**).

An attempt to determine transverse fields from polarization measurements in a broad spectral region was made in (**44**) by using the Unno theory for the calibration of these measurements in terms of field strength. The lines of force seem to be more tilted to the vertical in the penumbra of uni-polar spots than stated previously, and at the outer edge of the penumbra they are almost parallel to the solar surface (**44**). The possible influence of the polarization of resonance lines on these measurements of magnetic field has been recently considered in (**41, 42**).

Some estimates of the magnetic field in the chromosphere with the aid of Hα-filtrograms can be made, as was demonstrated in (**45**). Long-lived spots show that the decrease of the magnetic field is equal to 12 gauss/day (**46**).

3. *Motions inside sunspots.* Doppler displacements of the magnetically insensitive line $\lambda 5576{\cdot}10$ ($g = 10$) were measured over the regions of large and small spots. The measurements did not show appreciable shifts of the main line and the shifts $\simeq 6$ km/sec found earlier should be attributed to the 'line-flare' ('flags') appearing in the penumbra at high-dispersion spectra (**47**). It was noted that Evershed motions are not the only type of radial motions in spot groups (**48**). Line asymmetry has been measured and in the umbra a descending motion of 0·1 km/sec was found (**49**). Vertical downward components are also determined in (**50**). Measurements of line-of-sight velocities with the aid of a solar magnetograph gave small vertical (150 m/sec) and tangential (180 m/sec) motions. The general character of the motion is as if the field moved together with plasma along the lines of force (**51**). In (**37**) the lines of force were found not to coincide with the direction of motion. The inclination of the Evershed streaming has been determined in (**52**); at the inner border of the penumbra the angle to the surface is about 40°, and at the outer border the same angle is 12°. Iso-photometrical analysis of some lines in the Evershed pattern showed that the asymmetry corresponding to velocities of 2–3 km/sec appears only in the wings of metallic lines, while the core of the line remains undisturbed. This can be connected with a gradient of velocities. At the same time, some strong lines show asymmetry in the wings corresponding to 18 km/sec at the *same* level in the atmosphere, thus pointing to the complex character of the motion (a kind of crossing of different streams) (**52**). The fine structure of the Evershed-effect, when one measures the shifts carefully, displays itself in the appearance of discontinuities (**53**). The abrupt change in distribution of velocities near the border of the penumbra, as well as the complex fine-structure pattern of distribution of velocities inside sunspots, have also been recently reported (**54**).

Hα–filtrograms of the chromosphere show an inflow of dark features with the high velocity of 45 km/sec and at an inclination of 13° (**55**). By comparison of successive pictures of sunspots obtained with Stratoscope-I it was found that the bright knots of penumbra filaments possess a radial outward motion with a velocity of the order of 1–2 km/sec (**29**).

4. *Physical state of sunspots.* In 1956–57 photographs of the complete sunspot spectrum were made in the range 4000–8600 Å with the concave-grating (dispersion 2·5 Å/mm) of the Göttingen solar tower (diameter of solar image 23 cm) (**56**). A method of correcting the measurements for scattered light, taking into account the spot geometry, has been developed. The following results were obtained: (*a*) The intensity-ratio 'spot to photosphere' seems to show a discontinuity of about 12 per cent between 4500 and 5000 Å. (*b*) The boundary temperature (derived from the energy curve) increases from 2700 to 3600° as the area of the umbra decreases from 150 to 50 millionths of the hemisphere.

Physical conditions in sunspots on the basis of curves of growth were considered in (**57–59**).

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In (57, 58) an excitation temperature $T_{ex} \simeq 3900°$ is obtained, but in (59) the same value is estimated as 4220°. The radiation of four large spots as a function of wavelength and centre-limb position was measured and the temperature distributions calculated in (60).

According to (61), the low temperatures derived in (62) introduce difficulties in explaining the metallic lines, the only way out being to assume that current spectral observations are vitiated by an unsuspected amount of stray light. However, tests on the amount of stray light can be found in the sunspot spectrum itself, for instance by comparing the Zeeman patterns of neutral and ionized metals.

In an analysis (63) of the spectrum of a large spot, the continuum, the wings of the Balmer lines and the strength of metal lines were used to derive a new empirical sunspot model. It is characterized by lower temperatures than the 1953 model by Michard, but also predicts low pressure and high transparency of the superficial layers. The pressure reduced, as compared to the photosphere, may be balanced by the hydromagnetic pressure of the field.

The damping in the wings of strong metallic lines, as an estimate of the pressure in spots, has been analysed in (64), finding also that it is much lower than in the photosphere. In a further paper both temperature and pressure from a simultaneous study of the wings of the Na, D and Mg, b lines were derived.

The molecular lines have been studied in (65). In a comprehensive discussion of the bands of C_2, CH, CN, NH and OH in spots and photosphere the author tried to derive the pressure difference $\Delta \log P$ and the abundances of C, N, O, taking into account the large uncertainties in the dissociation potentials and f-values for some molecules and transitions. In this work the spot pressure is found slightly higher than in the photosphere.

The problem of 'turbulent' motions in sunspots has been investigated in (66) where the same values in umbra and photosphere were found, the velocities being smaller in the penumbra.

A model with hot (5700°) and cold components (4000°) in hydrostatic equilibrium was proposed (67). In (68), the existence of radiative equilibrium was doubted. The spots in the chromosphere were considered in (69), and the heights of the Balmer-line formations were measured and pressure determinations carried out. The possibility, and method of determination, of abundances by sunspot spectra has been suggested in (70). The influence of scattered light in the spectrophotometry of sunspots has been considered in (71).

5. *Theory.* Spot models without motions were computed under the conditions of magneto-hydrostatic equilibrium and inhibition of convection (72). A model for the penumbra was given in (73). If the magnetic field is nearly horizontal, convective rolls result, which are consistent with the known properties of the penumbral filaments. Under the assumption of a force-free magnetic field with axial asymmetry, a model of sunspots is given (74). In (75) was shown that in the spot centre the equation of hydrostatic equilibrium is correct even if there exists a small deviation from the vertical, and a small curvature of the central line of the spots' magnetic field. The energy transport in a sunspot was considered in (76); the convective energy transport is inhibited by a vertical magnetic field, Alfvén waves are reflected and the energy of these waves is dissipated by viscosity. The stability of magneto-hydrodynamic models was considered in (77).

In (78-81), theoreretical considerations of the influence of the choice of sunspot model and of the mechanism of line formation on the polarization properties of radiation in sunspots are given.

The absorption coefficient for the orthogonally polarized radiations, by taking into account the effect of abnormal dispersion in the presence of a magnetic field, is derived in (82). The effect of rotation of the plane of polarization due to abnormal dispersion, as well as to the change in orientation of the magnetic field, is considered in (80).

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Formulae for the profile and polarization of the Zeeman triplet in the Schuster-Schwarzschild model have been given in (**81**).

C. FACULAE, FLOCCULI AND ACTIVE CENTRES

Profiles of infra-red λ10830 line in absorption were observed photo-electrically in 22 solar plages. The ratio R (10 830)/R (10 829) $\simeq$ 4 deviates from the value 8, valid for the optically thin case, R being the central depth. The equivalent and total widths seem to increase towards the limb. The red wing of the profile extends farther than the blue one. The most probable velocity for the gas motions is 8·85 km/sec, which is considerably smaller than that of the undisturbed chromosphere (15 km/sec). This difference is attributed to the reduced (due to magnetic fields) turbulence in plages. The kinetic temperature in the Hα-plages cannot exceed 19 500 °K and excitation temperature is ~5000 °K, which indicates the significance of photospheric radiation in the line formation. The asymmetry can be due to the fine structure and to the fact that over relatively small areas the gases are descending with a velocity of the order of 10 km/sec. The number of ortho-helium atoms per unit of area is an order of magnitude greater in plages than in the undisturbed photosphere (**1**). A general description of plage areas and their relation to other solar phenomena has been given in (**2**). The relative motions of separate elements of fine structure in Ca II plages (knots) was found proceeding with velocities ~ 100 m/sec. The mean life-time of these formations is of the order of one hour (**3**).

The observed profiles of Hα and Hβ have been compared with theoretical profiles and good agreement between them was found if one assumes that the line is formed by 'true' absorption (**4**). The run of the contrast of faculae with wavelength was measured for different angles θ (the angular distance from the centre of the disk). The spectro-photometric gradients and temperatures are determined for different θ. The mean difference of temperatures (in the sense: faculae minus photosphere) is 450°K (**5**). The contrast faculae/photosphere was measured and a model of the faculae has been constructed. It is shown that the excess in flux in faculae can be explained by assuming that this excess is due to convective transfer of energy (**6**). X-ray photographs of the Sun's disk have been taken in the spectral range 10Å to 100Å (**7**). These reveal features of the low corona which resemble and roughly coincide with calcium plages. Maps of calcium plages, drawn with the help of the material collected at the World Data Center A (Arcetri Observatory) during the IGY, have been published (**8**). Character figures of calcium plages have been determined for the year 1960 (**9**) according to the material collected at the solar tower of Arcetri.

Some information about the magnetic field 10^5 km above an active region have been obtained from microwave-polarization in (**10**). The radio aspect (λ21 cm) of plage areas has been also studied in (**11**). Co-operative high-resolution studies of 10 cm active regions in the 3 cm to 21 cm bands, giving also the dimensions of the radiating regions, have been undertaken in (**12**). The heating mechanism of plage areas by magneto-hydrodynamic waves has been studied in (**13**). The general topology of the Sun's magnetic field, especially the formation and evolution of active regions, in terms of field loops lifted to the solar surface and concentrated into active regions, is discussed in (**14**).

The relation between the calcium K_{2-3} plage and solar radio emission of 1420 Mc/s, using the data of IGY and IGC was studied statistically. The position, shape and area of the calcium plages coincide quite well with those of the brightness contour of the intensive region of the radio emission (**15**).

D. FLARES

1. *Statistics.* A statistical investigation of the frequency of flares, appearing within sunspot groups of different classes and magnetic structure, shows that within sunspot groups of complex magnetic structure ($\beta\gamma$, γ) the flare frequency is considerably higher than in normal groups

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and that it is highest for sunspots containing several umbrae of opposite polarity within the same penumbra (**1**).

Statistically, flaring tends to prefer regions containing both polarities rather than unipolar areas within a spot group. About 10 per cent of the flares show clear or possible coverage of some part of spot umbra (**2**). The data covering the years 1937–59 and including 580 major flares were studied with attention to the relation between geomagnetic activity and flares. The probability of major geomagnetic storms is higher for the major flares appearing in the groups of complex magnetic polarity. Great-storm flares show unexpected concentration in the northern solar hemisphere (**3**). Active regions with flares producing cosmic rays (40 cases) have been considered with attention to possible peculiar characteristics. All flares appeared in magnetically complex groups. Over $\frac{2}{3}$ of the flares occurred: (*a*) in the northern solar hemisphere, (*b*) west of central meridian and (*c*) on first or second rotation. However none of the gross characteristics such as areas, heliographic co-ordinates, etc. distinguish the proton-producing areas from the others, (**4**).

Extensive statistical studies of different flare characteristics have been carried out at Sacramento Peak Observatory (**5–12**).

The study of the flare data published in the 'Solar-Geophysical Data' of G.R.P.L. showed that (*a*) there are some systematic differences among the participating observatories in the way of assignment of the importance to a flare from the observed max. area and intensity, and (*b*) in some cases, there are larger differences in the estimated importance of a flare observed by two or more observatories at nearly the same time (**178**).

The following figures illustrate the decline of flare activity with the approach to solar minimum conditions according to the data of flare patrol of the Royal Observatory, Cape of Good Hope.

No. of days of observations	Possible No. of days	Class = 1 −	1	2	3	3+	Total
1960 : 284 (78% of possible)	366	399	249	22	4	2	676
1961 : 296 (81% of possible)	365	170	112	10	—	2	294
1962 : 276 (76% of possible)	365	63	67	7	—	—	137

2. *Direct observations of flares.* Results of a search for 'white-light' flares, during the period July to October 1959, has been reported (**13**). No white-light flares were reliably detected and an upper limit of 10^{22} erg steradian $^{-1}$ Å^{-1} sec^{-1} was placed on the continuous emission of normal flares of class 2 (or smaller) at λ4900.

The observed data on the white light flare on 1960 November 15, was reported (**176**). Cinematographic (with the monochromatic heliograph of Lyot) and radio observations at 9500, 800, 408, 200, 160, 100 and 67 Mc/sec, and also at 9400, 3750, 2000, and 1000 Mc/sec were carried out.

A morphological and photometric catalogue of 130 flares recorded during IGY with Hα-heliographs in Meudon and Haute-Provence has been prepared. It contains sketches relating the evolution of the flares in relation to spots and filaments, light curves and remarks (**14**). A statistical discussion of the above data has been made. It shows that about $\frac{2}{3}$ of flares start over sunspots, generally over penumbrae. The strong tendency of flares to start simultaneously (or at very small time intervals) at a number of different points is emphasized. Many results of various significance have been derived or verified from this random sample of well observed flares (**15**). The dependence area-maximal brightness is found for most of the 200

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cases of flares except those where long bright ribbons are formed. Most of these flares show dependence between area and life-time (**16**).

The areas of 57 flares (observed in 1960) were measured and the area-curve of each flare discussed. The increase of area, at the pre-maximum stage, is linear and the time lag of maximum area after the maximum intensity is about 2·5 m on the average for larger flares, but almost zero for smaller ones (**177**).

The development and other characteristics of the ten cosmic ray flares, generating high-energy protons and producing ground level effect, were considered (**17, 18, 126**). These cosmic ray flares were notable for the flash of radiation in $H\alpha$ occurring in a time of the order of 2–3 minutes, the large area $\sim$ 2000 millionths of the hemisphere, the twin bright filaments crossing the spot group and running parallel to the magnetic axis, and the obscuration of the umbrae with highest field strengths.

The $H\alpha$-light-curves, for 44 flares of importance 2, are presented noting some of the regularities in behaviour of flares in $H\alpha$ (**19**). From investigations of the behaviour of 50 limb flares on $H\alpha$-films, the conclusion is drawn that some flares degenerate into prominences in the course of their development (**20**). The increase of intensity in the base of limb flares usually precedes the dilation of the bright flare surge (**21**). A part of a limb flare of 1961 September 16 was detached from the chromosphere and rose with a velocity of 1400 km/sec (**22**).

Bright clouds of some flares (e.g. those of 1959 July 14) are sometimes moving in picture plane as a whole with high velocities (**23, 24**). The motions of filaments and clouds have also been noted (**25-27**) and in several cases the bright ribbons of flares cover the very umbrae of sunspots (**26**). For some flares, 'impulsive' propagations with velocities 1000–2000 km/sec are found. The other flares show velocities of development of 100–150 km/sec (**27**). In one case of an eruptive prominence having the limb flare in its base, the propagation of bright luminous points with velocity 1500–2600 km/sec was observed (**28**).

3. *Magnetic fields of flares.* The positions of flares with respect to a magnetic field was considered (**29–32**). The bright ribbons of flares appearing in phase with maximum development of flares are found to be parallel to the 'magnetic axis' of sunspot group (**29**). The comparison of the positions of 15 great flares with detailed magnetic data of the corresponding sunspot group showed that the bright filaments of the flares tend to be parallel to the line $H^{||}=0$ or to the asymptotic line of force of transverse field joining the polarities of the same sense and neutral point (**30**). Some important flares appear in the region of appreciable longitudinal fields (**31, 47**); however the comparison of their location with combined maps of longitudinal and transverse fields shows that in every case we have some peculiarity in the behaviour of the lines of force, a kind of crossing or contact of oppositely directed fields (**32**).

The motions of flares with respect to the magnetic field have been investigated (**33, 25, 34, 35**). Two types of motion can be observed: (1) the dilatation of bright flare material along the line $H^{||}=0$, (2) the development of separate clouds in the region of only one polarity is proceeding in such a way as if the crossing of line $H_{||}=0$ were prohibited (**23**). The broadening of flare filaments is slow in the regions of strong fields (inside sunspots), and rapid expansions of flare clouds are observed outside groups (**35**). The flare filaments joining neighbouring spots of opposite polarity tend to be parallel to each other (**36**).

More direct evidence has been obtained about the changes of magnetic fields associated with flares. Changes of gradients of magnetic field and of magnetic energy were found after one 1_+ flare, but soon afterwards these values recovered to the pre-flare values (**31**). The changes of field associated with some flares were observed (**25, 37**), and the temporary drops of field strength in spots connected with flares were observed in 1960–61 (**38, 39**), and also in 1959 (**40**). In contrast with these observations, some authors (**36, 41**) concluded that magnetic fields during

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some flare events (in particular for great flares of 1959 July) did not undergo changes because the form of recurrent flares remained almost the same and flares appeared practically at the same places. However, the direct measurements of field gradients and magnetic energies showed considerable decrease of these quantities associated with the great 3^+ flare of 1959 July 16, and in some other cases, although the form of magnetic field relief and of the flare remained almost the same as in the cases of other flares in this group. The observed change of magnetic energy ($\sim 10^{32}$ergs) can be accounted for by the observed energy output of cosmic rays (**42, 43**). The analysis of extensive magnetic data before and after the flares for 52 flares of different importances showed that gradients of field before the flare are appreciably higher than those after the flare and that there is a good correlation between the gradient before the flare and the importance of flare: there are no flares of importance 3 with gradient of 1 gs/km nor flares of importance 2 with gradient higher than this value. These facts are closely connected with the change in the configuration of sunspots during flares, the configuration being more expanded after the flare (**43**). It has also been found (**44, 45**) that great flares produced changes in intensity and distribution of the Hα-plage regions and this is attributed to a change in the magnetic distribution of the region due to the flare process.

The shifts of magnetic hills on the maps of longitudinal fields and the corresponding shifts of sunspots on the photo-heliograms towards the flare before and during the event have been observed (**46, 43, 25**). From these shifts, the change of magnetic energy is determined as 10^{32}ergs (**46**), which is mainly converted into cosmic rays.

The appreciable changes of longitudinal and transverse magnetic fields during flares of importance 2, on 1962 July 21 and 22, have been recorded (**47**).

The remarkable influence of large flares on the fibrile chromospheric structure have been revealed. On several occasions this structure became blurred and almost disappeared near the maximum of Hα-brightness of flare and recovered after the flare. The phenomenon is attributed to the 'destruction' or diminution of magnetic field during flares (**48, 49**). The appearance of a dark halo (nimbus) at the maximum brightness, considered previously as an optical manifestation of the relativistic electrons producing type IV continuum radiation, is reconsidered (**44**) with the result that the effect of halo is essentially the same as the effect of destruction of striation pattern by flares (**44**).

A similar effect has been pointed out (**50**). An example of chromospheric striation obscuration by great flares was given (**51**).

4. *Spectra of flares.* The mechanism of broadening of emission lines in flares has been considered in a number of papers. The line profiles in flares at the limb and in moustaches are found to be in good agreement with Doppler (gaussian) profiles or with the profiles produced by a jet or a bulb with constant gradient of velocity (**52**). Doppler profiles or the sum of two Doppler profiles have been used to describe observed profiles in some disk-flares (**53, 54**). In some flares 'non-maxwellian turbulence' is found to be responsible for the broadening of lines (**55**). The effect of 'non-maxwellian turbulence' is interpreted as a result of the change of the Doppler width with depth (**63**). Stark-effect was found to be responsible for the broadening in some other cases (**57–61**).

Some explanation of these controversial results has been given (**62**) where the broadening of hydrogen lines in laboratory pinched discharge has been examined. Spectra of high intensity discharge were photographed with the échelle spectrograph currently used in flares observations. The analysis of profiles of extremely broad Balmer lines shows that, along the axis of the discharge, the broadening is due to macroscopic motions with velocities up to 1000 km/sec, and, across the discharge, the main contribution in the broadening is due to Stark-effect.

Moreover, the character of broadening can change during the flare development. For instance, for the flare 1958 July 20 the profiles of the hydrogen lines can be described by the

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formula $J \sim e^{-(\Delta\lambda/\Delta\lambda_D)^m}$ where m is changing from ~ 2 at the maximum to some $m < 2$ for pre-maximal phase and after the maximum (**63, 64**). In the great disk flare of 1960 November 12 the hydrogen lines were broadened by 'non-maxwellian turbulence' before the maximum and by Stark-effect after the maximum (**65**). The change of relative equivalent widths was also found to be characteristic of some flares in the course of their development (**53, 54, 66**).

Hydrogen and metallic emission lines reached maximum intensity at the same time for a flare, according to (**67**). The same authors found that the position on the disk of the bright wings of the hydrogen emission lines is shifted with respect to the position of the brightest emission in the core of these lines which coincides practically with the position of metallic line emission. The time sequence in appearance of hydrogen and metals in limb and disk flares showed that hydrogen and helium (originating at higher levels) reach maximum intensity first, and then, a few minutes later, metallic lines (at lower levels) become brightest and afterwards rare Earth lines reach their maximum (**68, 69**). This can be interpreted as the result of excitation produced by a shock-front propagating downwards to the chromosphere.

In (**70-73**), a series of investigations of limb flares and prominences is carried out. The electron temperature $T_e \sim 10\text{–}20 \times 10^3$°K and the electronic density $n_e \simeq 10^{11}$ cm^{-3}, are determined from the measurements of the Balmer continuum. Meanwhile the temperature derived from line-width is considerably higher. This discrepancy is concerned with the statement that emission lines in limb flares are broadened by macroscopic motions.

The great discrepancy of the values n_e for limb (10^{11} cm^{-3}) and disk (10^{13} cm^{-3}) flares and the comparison of the values n_e with the number N_2 of two quantum atoms for disk flares lead some authors to a conclusion of the possible existence of a sub-telescopic (with the size $\sim$ 10km) structure of flares (**57, 59, 60, 74, 75**).

The rich material of flare spectra at Ondrejov, (**67, 76, 77, 78**) was used for a qualitative discussion of the Hα and K-line widths, their centre-to-limb variation, Balmer lines excitation, and metal lines intensity. The brightest and most excited parts of flares were found at the border of penumbra. A study of the line asymmetry has led to the conclusion that this effect decreases towards the limb (**77, 79**). In some metallic lines, a splitting was discovered, which was originally explained as due to Zeeman-effect (**80**), but later on ascribed to the effect of self-absorption (**78**). The discrepancy between the values of the temperatures derived from the lines of different elements has led some authors to conclude the coexistence in flares of filaments with different temperatures (**53, 70, 81, 82, 83**).

In (**53, 56, 84, 85**), kinetic temperature T_{kin} and turbulent velocity are derived from the comparison of the lines belonging to the elements of different atomic weight. In (**86**), it is shown that such temperatures can be in error for the disk flares due to the stratification of emission of different elements in flares.

The calculations of the physical conditions necessary for Hydrogen emission in flares are carried out in (**74, 81, 87**). The Hydrogen spectrum of flares is explained as due to cascade transitions by electronic impacts at the temperature $T_e = 15\,000°$. In (**75**), the electronic temperature was found not to exceed 10 000°K.

The excitation of He in flares has been considered in (**83, 88, 89, 90**). The observed emission in para- and ortho-helium lines of He I can be secured by electronic impact and recombinations at $n_e = 2 \times 10^{13}$ cm^{-3} and $T_e \simeq 1{\cdot}7 \times 10^4$ °K as shown in (**89**). The same conclusion has been drawn in (**88**). Here the electronic temperature T_e for He II is evaluated as 40 000 °K. The conditions necessary for the appearance of He-lines in emission on the disk are considered in (**90**). In (**83**), the emission of He II in flares which can be condensed out of corona is explained by recombinations at $T_e = 100\,000$ °K. The observed emission of Na in disk flares can be explained at $n_e \simeq 10^{13}$ cm^{-3} and $T_e \simeq 2 \times 10^4$ °K as it follows from considerations of stationary equations for this atom. At the same time the observed emission of Ca II-atoms can be

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produced in a wide range of values of n_e and T_e (**91**). In (**92**), the spectroscopic criterion for discrimination of flares and prominences is introduced as the ratio M of the intensity of Fe II, λ4584, to the intensity of Ti II, λ4572. For the prominences $M < 1$, while for flares $M > 1$.

The Hα-line in spectra of flares was studied in (**93**), and the K-line in a flare spectrum in (**94**). In (**95**) the behaviour of He, λ10830, in flares, prominences and some other active formations on the Sun are considered.

A list of emission lines in a flare spectrum was given in (**96**, **67**, **69**, **76**). Shifts of more than 100 absorption lines in the vicinity of moustaches was considered in (**97**). The influence of seeing on the flare line profiles was noted in (**98**). An unusual flare, probably situated very deep in the photosphere, was described in (**99**).

In (**100**) the coronal spectrum at the place of the limb flare of 1960 November 20 has been considered.

The spectral characteristics of proton flares (producing cosmic rays) have been found to be practically the same as those of usual flares (**101**).

The unusual recurrent flare in the form of emission of H and He-lines in the spectrum of a sunspot was observed in (**102**, **103**). Relationships between Hα-intensity, width, and area of flares, were studied in (**104**). Reviews of recent works on spectroscopy of flares are given in (**105**, **106**).

5. *Flare-associated phenomena* (*optical*). Dark ejections, especially during flares of complex structure, have been observed. These ejections behave in such a way as if they avoided the luminous areas of flares. The ejections are located between the regions of opposite polarity (**107**). The loop-like dark filaments appear during the maximum of flare development and afterwards, and they remain visible up to the end of flares closely associated with sunspots (**108**). The connection between the type of flare development and dark ejection activity is found: the explosive-like flares are accompanied by rapid ejections, while the slow developing flares are associated with slow outflow of chromospheric material and with the formation of loop-like prominences. Flares with pulsations of Hα-intensity and recurrent maxima are accompanied by coronal streamers (**109**).

Dark ejections are found to appear during the whole life of a flare and their appearance is always connected with the brightening of the existing knot of a flare or with the appearance of a new bright cloud. All ejections are closely connected with the penumbra and even with the umbra of sunspots (**110**). The intensification of ejection activity during flares is also accompanied by the rise of the gases at the phostospheric level according to magnetographic records of radial velocities (**110**, **25**).

Filament activation as well as high-speed bright surges associated with the flares of 1926 February 22 and 1956 February 23 have been described in (**50**). The 'disparition brusque' phenomenon associated with flares observed on Kodaikanal Hα-spectroheliograms has been studied in (**111**). The flare disturbance responsible for 'disparition brusque' seems to have an anisotropic propagation. In some cases it has been observed that filaments close to the active flare region remain unaffected, while distant filaments show either activity or 'disparition brusque' or both. From spectrohelioscope observations at the Nizamiah Observatory, the observers report (**112**) on the activation of a dark filament by the 1^+ flare of 1957 November 15. The speed of the filament traverse is found to be 1000 km/sec.

An extensive catalogue of disappearing filaments (disparitions brusques), flare sprays, and loop prominences for 1955–60, observed at Sacramento Peak, has been published (**113**). Evidence has been offered that all loop prominences, which are known to coincide with *sporadic* coronal condensations, originate in great solar flares. Lifetimes and other characteristics of these loops have been studied (**114**, **115**). The long-lived coronal condensations, on the other

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hand, appear to be impervious to the effects of even great flares (**116**). The percentage of surge-associated flares to all the observed flares increases as the flare importance becomes greater: *one minus:* 9%; *three*: 71%. This ratio, however, is approximately uniform, when the category of statistics is extended to all kinds of prominence activities including surges, active prominence and active filament regions: *one minus:* 37%; *three:* 43% (**117**).

Information has been presented showing the formation of flare filaments coinciding with bursts of decimetric radio emission and production of ionizing X-rays (**118**). Limb surges have indicated that X-rays may be emitted from substantial heights above the photosphere (**119**). Similarly, evidence has been given for X-ray emission and radio noise emission from eruptive prominences (**120**).

Neutral and ionized helium lines of the limb flare of 1960 April 5 were intensively studied. Concentrations of different temperatures were noted in the same places where the corona showed intensifications of brightness, and they had the same form (**121**).

A flare spray prominence moving through the corona was found to move along the outlines of a pre-existing coronal arch visible in the 5303 Å green coronal line (**122**).

Numerous studies of physical conditions, presumed to occur in the corona overlying a flare, have been attempted. Consideration of the 1960 September 4 flare led one author to endeavour to draw together a comprehensive picture of the radio emission, X-rays, high-ionization coronal lines and the particle emissions (**123**). Another has attempted to tie the origin of flares to a sudden collapse of hot yellow coronal line emission regions (**124**).

A complex limb flare of 1960 August 20 was found to be accompanied by two types of ionizing radiation. Hard X-rays persisted for about 10 minutes, and soft X-rays for about 40 minutes (**125**).

A cosmic ray flare of 1961 July 18 developed a Y-shape, and its filamentary changes suggested a possible path of cosmic rays escaping from the flare (**126**).

Studies of the large flare of 1961 September 28, 22^h02^m U.T. (**127**) have thrown light on the questions of generation of X-rays and high energy protons in the solar corona.

Flares that exhibit explosive development have been shown to associate more closely with high energy solar X-rays, (**128**), and with short-wave fade-outs and 10-cm radio noise bursts (**129**).

6. *Flare-associated phenomena* (*radio-emission*). The most important radio burst associated with solar flares is the type-IV radiation which is a continuum observed throughout the observable frequency range. A great deal of work has been done recently on the spectral and directional characteristics of this radiation and on its classification into several physically distinct phases (**130–139**). It now appears that one observes three distinct phases in the evolution of type-IV radiation as a whole.

In the first phase, known as type IV A, almost simultaneously with the flare, the continuum emission starts on centimetre and decimetre waves. It is partially circularly polarized and its source, narrow in diameter ($< 4'$ arc), is situated low in the corona (at heights of less than $\sim$ 40 000 km above the photosphere) and does not exhibit any significant motion. The decimetre-wave continuum has been considered by some authors (**131, 139, 134**) as a distinctive phase because of its large variabilities and its characteristic mode of polarization (ordinary mode as compared to the extraordinary mode of centimetre and metre-wave continuum). The variabilities are, however, found to be mostly fast drifting elements superimposed upon a background continuum which has characteristics very similar to that of the centimetric continuum (**140**). Because of this, observation and the fact that the change of polarization can be explained by a propagation phenomenon, the decimetre-wave phase is now considered (**136**) as identical with the centimetric phase (type IV A).

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The second phase, or type IV B, which occurs when the first phase is strong, is the classical type IV radiation occurring on metre and decametre waves. It is usually associated with, and preceded by, a type II radio burst. Its source, large in diameter (7′–12′ arc), does not remain fixed in the corona but moves with velocities of a few hundred to several thousand kilometres per sec. Both type IV A and type IV B are believed to be caused by synchrotron radiation of electrons released and accelerated during the flare. The synchrotron radiation of electrons trapped low in the chromosphere in the sunspot magnetic field is responsible for type IV A radiation. The type IV B radiation occurs high in the corona; it is believed that at the start of the flare a cloud of gas is ejected, and because of its high velocity, a shock front is generated ahead of this cloud. The cloud with its shock front, which successively excites plasma oscillations, moves at high velocities and carries a frozen-in magnetic field to the appropriate heights in the corona, enabling the electrons to emit synchrotron radiation, which is observed as type IV B radiation.

The third phase, or type IV C, occurs on metre and decimetre wavelengths, as a prolongation of the type IV B event, particularly when the flare, as well as type IV A emission, is very strong. It is distinguished from type IV B by its high directivity of emission and its ordinary sense of polarization as compared to the extraordinary mode of type IV B bursts. Further, its source, small in diameter ($\sim$ 4′ arc), remains practically fixed in the corona (at heights of $0{\cdot}2-0{\cdot}4\,R$ above the photosphere). Its interpretation is still controversial, and both synchrotron and Cerenkov plasma radiation have been proposed to account for this radiation (**131, 141**).

It appears that the covering of the umbra by a flare is important for its association with a type IV event and its eventual production of cosmic rays (**142–144**). Important information concerning the centres of noise storm radiation and its interpretation has been obtained recently (**145**).

The impulsive bursts on centimetre wavelengths (which belong also to type IV A) are very closely associated with high-energy X-ray bursts ($>$ 20 keV) and it is believed that the same fast electrons are involved in producing centimetre-wave burst by synchrotron plus Bremsstrahlung mechanism and X-ray burst by Bremsstrahlung mechanism (**146**).

Recent positional measurements of type II bursts (**147**) indicate that type II bursts are much more complex than they appear to be from spectral data alone. The differences in position and frequency drift rates at different parts of a type II burst spectrum suggest that a single type II burst may, in fact, be composed of multiple bursts which are excited by multiple shock fronts which, ejected successively from the flare region, follow different trajectories through the corona with different speeds. Further, the relative positions of the fundamental and second harmonic bands of type II and type III bursts indicate that the harmonic emission is generated preferentially in the backward direction, as a consequence of the longitudinal plasma waves being transformed into electromagnetic radiation by combination scattering on charge fluctuations in the coronal gas (**148**).

Type II radio bursts have been found most probably to delineate hydromagnetic shock fronts which move in the solar atmosphere from the associated flare in a manner determined by density and magnetic field considerations. There is hope of deducing the structure of the coronal magnetic fields if higher resolution is brought to bear on the deployment of type II and type III radio burst emissions (**147, 149**).

The suggestion has been made, based on the frequency drift of type II bursts (**150**), that they are caused by a disturbance propagated at a speed of 1000–1500 km/sec outward from a flare region along a coronal streamer in which the electron density is ten times that of the Baumbach-Allen model corona. In such a streamer, assuming a coronal temperature of 10^6 °K, the workers from the same laboratory found type III bursts to exhibit radial components of velocity of the

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order 0·4 c; at the same time, they found that the source disperses as it moves outwards (**151**). The correlation between type III bursts and flares and sub-flares indicates that particle acceleration is a part of the flare process (**152**).

A precise comparison between the record of Gradual Rise and Fall in the 10·7cm radio flux record observed on 1958 June 28 at Ottawa and the variation of the plage area in the flare patrol photographs at the Sacramento Peak Observatory was made. The result is that the Gradual Rise and Fall burst is not an enhancement of the slowly varying component, but is originated from the base (weak flare region) of a temporary loop of matter which extends upwards between two sunspots (**179**).

7. *X-rays from flares.* The most important measurements of flare X-rays were direct rocket and satellite experiments on the records of $L\alpha$ and X-rays outside the Earth's atmosphere (**153, 154**). Simultaneous measurements of $L\alpha$ and X-rays (in the range $\lambda < 8$ Å) showed that $L\alpha$-flux remains practically unchanged (or rising no more than 10%) while X-ray flux shows increase (10 times or more) during flares. Not only flares but active prominences, bright surges and small limb flares have the same X-ray characteristics as disk flares. An X-ray event has even been recently recorded without any optical response according to (**161**). SID effects occur when the X-ray flux ($\lambda < 8$ Å) exceeds 2×10^{-3} ergs/cm^2 outside the Earth's atmosphere; significant changes in X-ray fluxes can take sometimes a very short time-interval, of the order of one minute.

The detailed comparison of SID produced by solar flares with centimetre and metric bursts of radio-emission leads to the following results: The time sequence of SID events and events in radio-emission is almost the same, but there is some time lag in the start of these events as compared with the start of Hα-flare (**156–160**). The radio bursts of type IV are accompanied sometimes by considerable ionospheric effects (**159**). Some SID are probably connected with flares appearing behind the limb (**159–161**). There are no dependence of ionospheric effects produced by flares and their position on the disk (**158–160**).

The considerable changes in distribution of electronic density in the D-layer can be due to flares (**162**). The approximate spectral composition of X-rays generated by flares can be derived from the frequency dependence of cosmic noise absorption, and this composition found to be different for different flares (**163**). Some flares (1958 March 23; 1959 July 14; 1960 April 1; 1960 November 12) are characterized by considerable amount of X-rays in short-wave length region (0, 1 to 1 Å) and by steep decrease of the intensity of X-rays towards the longer wavelengths (**163**). The flux of X-rays for the region 2–10 Å is estimated from these measurements as 10^{-3}ergs cm^{-1} sec^{-1} (**162**).

8. *Theories of flares.* The Sweet mechanism of approach and merging of two oppositely directed fields has been recently discussed in detail by taking into account all possible factors capable of accelerating the process of diffusion (**164**). It is shown that, in the best case, the process takes a time of 10^4 sec, which is too slow. To avoid this difficulty, the concept of flare as consisting of many small-scale flux-tubes of mixed polarity has been put forward (**165, 166**). The time of dissipation of magnetic energy in this case can be reduced to the proper magnitude, but this turbulent-magnetic dissipation can occur only after the kinetic energy of the process becomes available for twisting magnetic fields by a collapse of large-scale fields.

The contraction or condensation of plasma appearing in equilibrium at the neutral point of a given configuration of the external dipole-field (of sunspots) caused by the change in the position of sunspots or by their field strength has been considered in (**167**). It is shown that strong shocks converging to a neutral point can appear as a result of such a contraction. The boundary conditions in this problem has been a subject of some argument between (**168**) and (**169**).

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The possible mechanism of acceleration of particles between magnetic walls approaching to the neutral point was considered in detail in (**170**). The acceleration of particles under the action of a solitary shock moving in a non-uniform field has been considered in (**171**). The expression for the rate of intensity increase in the case of a shock-front out-running at the surface of the solar atmosphere has been derived, and the time of the process evaluated (**172**).

Continuum electromagnetic radiation from flares has been studied in terms of the energy-loss processes of electronics in the solar atmosphere. It was shown that it is possible to attribute the continuum radiation both at radio- and visible-frequences to synchrotron radiation by exponential rigidity distributions of electrons (**173**).

Betatron mechanism for acceleration of protons to cosmic ray energies has been proposed in (**174**). A modification of betatron acceleration of electrons between hydromagnetic waves crossing each other has been proposed in (**175**).

E. PROMINENCES

The statistics of the occurrence of limb prominences, and the east-west limb asymmetry of prominence frequency, have been studied further (**1, 2**).

In (**3**) has been studied the motions in small, dark, prominence-like features located just outside the penumbrae of sunspots, using observations made on either side of the Hα line through a tunable 1/8 Å bi-refringent filter. The average velocity was about 45 km/sec in a direction inclined at 13° to the solar surface. Since the lifetimes of the dark features are very long compared with the time required for material to flow along their length, they are interpreted as long-lived channels along which chromospheric material flows into the spot.

An analysis of eight well-observed eruptive prominences in the 57-years Kodaikanal collection shows that all parts of a prominence adhere to a general pattern of motion with small significant deviations (**4**). Sky-plane components of the trajectories tend to be either of strong curvature or long and slightly curved. It is suggested that an eruptive prominence has a compound magnetic field, consisting of a stable weak field and a momentary strong component; and that the type of trajectory of erupting material is primarily decided by whether the equilibrium in the active prominence is destroyed, by the kinetic energy exceeding the magnetic energy or vice-versa.

Observations have been made that indicate variations in the intensity of quiescent prominence possibly due to disturbances from flares moving with speeds of about 80 km/s (**5**). Similarly, influences of surges sometimes appear to cause activations of quiescent prominences (**6**).

The emission rim around some filaments was investigated (**7**). This emission formation is found below the prominence or filament in the chromosphere and the emission excess of this rim is 10–15% of the surrounding chromosphere.

The magnetic fields of active and quiet prominences are evaluated as 200 gauss and 50 gauss respectively from the observations with the magnetographs (**8, 9, 10**).

Spectroscopic criteria for the differences between flares and prominences, or between active and quiescent prominences, continued to receive attention (**11, 12**). Behaviour of the infra-red helium line (λ 10830 Å) has been compared in various solar phenomena (**13**), including the profile in flares and prominences.

In (**14**) the profiles of the H- and K-lines of ionized calcium in quiescent prominences are investigated, and it is found that the observed line-widths for these lines are much greater than those predicted, assuming only thermal broadening. The large line-widths of the Ca-lines compared with Hα indicate broadening by a non-thermal process.

The principal mechanism of excitation of the lower quantum levels of the Balmer series in

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prominences is excitation by photospheric radiation according to (**15**). For the higher members of this series the role of electronic impact and recombination may be important.

The calculated relative intensities and profiles of some Balmer lines in prominences have been found to be in agreement with observations (**16**).

The weak metallic lines in prominences are excited by photospheric radiation according to (**17, 18**).

A graphical method for accounting for the self-reversal of emission lines in prominences is presented in (**19**).

Detailed spectral data about metallic-line prominences are given in (**20**).

The polarization of the K-line 3933 Å in prominences has been observed by a D.C. photoelectrical method. It is shown that in quiescent prominences the polarization of the K-line increases with the altitude above the chromosphere. In active prominences the K-line is much more polarized than in quiescent ones (**21**).

Condensation of prominences has received attention from a number of authors. A diamagnetic effect of the solar cosmic ray streams in the corona near sunspots has been suggested as a possible trigger for prominence formation (**22**). Observational and other evidences on condensation processes have been presented (**23, 24**).

A study of active prominences has shown that 90% were followed by bursts of solar radio radiation, about 60% by partial or complete short-wave radio fade-outs and about 7% to 20% with S.E.A. or S.C.N.A. Thus prominences of high activity are also sources of enhanced solar radio radiation and X-rays (**25**).

Models of solar prominences illuminated by ultra-violet radiation from the chromospheric or coronal Lyman continuum radiation of hydrogen have been examined by different authors (**26, 27**).

Inhomogeneous models of prominence emission, with two regions of emission, one hot and one cold, have received substantial attention from various authors in an effort to explain line and continuous spectra, particularly of quiescent prominences (**28–32**).

Models with radiative energy losses supplied entirely by thermal conduction from the corona (**33–35**) have exhibited promising results, but will remain somewhat obscure until the heating mechanisms of the corona are better understood.

The suggestion was made of a 'quasi-corona' between a quiescent prominence and the surrounding dark dome of the corona (**36**).

F. CORONAL CONDENSATIONS

Using, as a basis, previously published K-corona observations made at Climax, Colorado, a model has been derived for the enhancement of electron density in the corona above an active region. The electron densities in the quiet corona during the sunspot maximum of 1957–58 were found to be about twice those reported by van de Hulst for a maximum corona, while densities along the axis of the active region were found to be about twice those in the quiet corona at the same height. The several models advanced in the past to explain the slowly varying component of solar radio radiation are criticized mainly on the basis that they require coronal temperatures of from 6 to 10 × 10^5 K, while there is no evidence for the existence of such temperatures (**1**).

Based on the statistical relations between intensities of three coronal lines (5694 Å, 5303 Å, 6374 Å) and the average flux density at 1420 Mc/sec intensive regions, a model of the coronal condensation is obtained. The model consists of two parts, namely, a core part and a surrounding part. The core part appears to have a very high electron density ($> 50 \times 10^8$) and a very

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high electron temperature (4×10^6K), where the yellow coronal line (5694Å) and the high brightness temperature at 1420 Mc/sec originate. The surrounding part appears to have a high electron density ($> 10 \times 10^8$) and to consist of two different temperature elements ($1{\cdot}7 \times 10^6$K, $2{\cdot}4 \times 10^6$K), where the intensities of the green (5303Å) and red (6374Å) coronal lines are stronger than in the normal region, and where the main source of the flux density at 1420 Mc/sec lies (2).

The shape and the dimensions of 45 coronal condensations have been derived (3) from observations in the yellow coronal line $\lambda 5694$ of CaXV. The condensations seem to be more closely connected to the plages than to the spots.

The electron density and the electron temperature of the coronal condensation by the optical observation at the total eclipse of 1958 October 12, in the South Pacific were determined. The electron density at 100 000km was about ten times higher than that in the normal corona. At a point higher than 80 000km, the temperature was found to be higher by a few hundred thousand degrees than that of the surrounding corona (4).

From the eclipse data of 1952 February 25, an inhomogeneous model of a coronal condensation with four temperature components from $0{\cdot}45$ to $2{\cdot}5 \times 10^6$ °K has been obtained. The volume fraction of each component was estimated, but the lowest temperature component does not show a maximum volume fraction at the edge (15×10^4 km from the centre), but at $4{\cdot}5 \times 10^4$km from the centre of the condensation. The abundances of iron and nickel (relative to hydrogen) were found to be about ten times higher than those obtained in the photosphere (5).

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President of the Commission

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