10. COMMISSION DE L'ACTIVITE SOLAIRE

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The research activity in the field of Commission 10 has been enormously increasing as one can easily observe when comparing the present list of references with the Draft Reports of the preceding three-year periods. Therefore, some limitation of the contents of the Draft Report is necessary. We have not included any paper presenting only observations without any discussion of them and as the solar-terrestrial physics is concerned, only those papers are included, which contribute to our knowledge of the Sun and its wave and particle emission. That means that we have not mentioned here the numerous papers which treat the influence of the solar activity on the terrestrial magnetosphere, ionosphere and troposphere, unless some information on the problems of solar physics or solar cyclic variations can be deduced from them. We have included all the remaining papers concerning solar activity published since the beginning of 1964 and very few papers which appeared in 1963 and clearly could not be included into the last Professor Severny's Report.

Most of the members of the Organizing Committee and many members of the Commission participated in preparing the Draft Report. Particularly: Section 6 is based on the report on sunspots prepared by W. Mattig, section 8 on the report on prominences prepared by J. T. Jefferies, section 9 on the report on the active corona prepared by J. Rösch, and section 10 on the report on active radio phenomena prepared by A. D. Fokker. E. v. P. Smith substantially contributed to sections 11, 12, and 13. A. B. Severny's report on magnetic field measurements has been used extensively when preparing sections 4, 6, and 7.2. A. B. Severny and N. V. Steshenko also provided me with a list of references and abstracts of papers published in the U.S.S.R. and S. Nagasawa informed me in a similar way about papers published in Japan. A detailed report on terrestrial effects of solar activity prepared by C. Sawyer unfortunately arrived too late to be included in this Report. My thanks are due to all these contributors as well as to all other solar physicists who have provided me with useful information on the recent progress of their work.

1. GENERAL PROGRESS REPORT

1.1. *International projects*

During the reported period four international projects were organized, closely connected with problems of solar activity:

International Years of the Quiet Sun (IQSY) started on 1 January, 1964 and lasted for two years. From the point of view of solar physicists, the main aims of IQSY were (1) to maintain a complete patrol service during the period of the solar minimum, and (2) to profit by observations of fairly isolated active processes on the Sun both as the study of solar active regions and the solar-terrestrial physics are concerned.

The study of isolated active regions was the main purpose of the Cooperative Study of Solar Active Regions (CSSAR), organized by R. Michard for half a year during the IQSY period, from 1 April to 30 September 1965. Its main aim was to study the development of active regions without any disturbing effects of adjacent solar activity, with particular emphasis on the final decay of local magnetic fields.

Commission 10 also organized the Proton Flare Project (PFP) from 1 May to 30 September, 1966, with P. Simon as the Chief Coordinator. Very successful proton flare forecasts enabled to get many data on proton flares of 7 July and 2 September, 1966, and on the associated active regions.

The project on 'Rapid Variations of Solar Magnetic Fields' organized by V. A. Krat, had many features similar to CSSAR and PFP.

Final results of these projects had not yet been known when this Draft Report was submitted for press. It is supposed that the scientists responsible for these projects give general information on them during the Prague Assembly and some of the results will be reported at the IAU Symposium on the Structure and Development of Solar Active Regions in Budapest, in September 1967.

1.2. *Books and Symposia*

Three important books, of general interest for those working in the field of solar activity, appeared during the reported period: A monograph about sunspots by Bray and Loughhead (1964) gives a description of a wide range of sunspot phenomena and their interpretation. Kundu (1965*a*) published 'Solar Radio Astronomy' and gave here a very detailed account of our present knowledge of the radio emission from the Sun. And the book 'Solar Activity' written by Tandberg-Hanssen (1967) has tried 'to give a treatment of all the different manifestations of activity on the Sun in a unique framework: as the inevitable results of the interaction between solar magnetic fields and the solar plasma'. In all these books and most extensively in the last one, readers can find a very complete account of the results obtained in the last decade in the study of solar activity, with extensive lists of references.

Papers presented at six symposia, conferences and summer schools organized in 1963 or earlier, were published during the investigated period: The Symposium on Stellar and Solar Magnetic Fields = IAU Symposium No. 22 (Lüst 1965), the AAS–NASA Symposium on the Physics of Solar Flares (Hess 1964), the Plasma Space Science Symposium (Chang and Huang 1965), the Summer School 'Introduction to Solar Terrestrial Relations' (Ortner and Maseland 1965), the Utrecht Symposium 'The Solar Spectrum' (de Jager 1965*a*), and the 1st Consultation on Heliophysics at Tatranská Lomnica (Mergentaler 1964). The following meetings were held during the reported period: The Symposium on Astronomical Observations from Space Vehicles = IAU Symposium No. 23, 17–20 August 1964 (published in *Ann. Astrophys.* **27** and **28**); the Meeting on Sunspots in Florence, 9–12 September, 1964 (Righini 1966); the Meeting on Solar Magnetic Fields and High Resolution Spectroscopy in Rome, 14–16 September, 1964 (edited by M. Cimino; not yet published and consequently, some papers presented there could not be included in this Report); the 3rd Consultation on Solar Physics at Tatranská Lomnica, 13–16 October 1964 (Kopecky 1965*a*); Solar Physics NATO Summer Course at Lagonissi, 12–26 September, 1965 (Xanthakis 1966*d*); Colloquium on 'The Fine Structure of the Solar Atmosphere', Anacapri, 6–8 June, 1966 (Kiepenheuer 1966*b*); the Inter-Union Symposium on Solar-Terrestrial Physics in Belgrade, 29 August–2 September, 1966 (not yet published); and the 4th Conference on Solar Physics held in Sopot and organized by the Wroclaw Observatory in September 1966 (not yet published).

1.3. *Scientific progress report*

(For details, see sections 2–14).

Remarkable progress has been made in our understanding of the general development of active regions. It seems to be clear enough that all solar magnetic fields are basically bipolar units and that the supergranular pattern of the solar atmosphere plays a fundamental role in the development of active regions. The rapidly improving techniques of magnetographic measurements has permitted to resolve relatively homogeneous magnetic fields in complicated multipolar structures and to detect the very fine structure of solar magnetic fields with height in the solar atmosphere. Strong fields in small limited regions in the photosphere as well as isolated chromospheric fields are of particular interest. Chromospheric pictures obtained with the domeless coudé refractor at Anacapri (Kiepenheuer 1966*b*) give an example of the progress achieved in the photographic study of the fine structure of the solar chromosphere.

When studying sunspots, one still meets with the most serious difficulty of the stray light, which contributes more than 50% in the umbra light. Both the experiments carried out with balloon-borne telescopes as well as new methods of theoretical analysis proposed by several authors, have tried to solve this problem. Nevertheless, some of the results of theoretical analyses are still in contradiction, particularly as to the existence or non-existence of sub-hydrostatic pressures in sunspots. Magnetographic measurements indicate the existence of twisted fields in sunspots. Generally, the variation of the magnetic field strength with distance seems to be similar to that of a dipole submerged beneath the photosphere, at least as the intensity distribution is concerned. Great attention has been paid to the fine structure of the Evershed effect, but the authors did not arrive at a unique solution of the problem. Progress has been made in the difficult transfer problem for lines formed in the magnetic field, where solutions have been obtained for greatly generalized conditions.

Attention has been paid to variations of the magnetic field associated with flares as well as to the location of flares with respect to the magnetic field. While our knowledge of the first problem has not significantly improved since the last Draft Report, several authors now agree that flare brightenings are distributed along both sides of a neutral line of the field and usually extend parallel to the neutral line, in their later development. A remarkable progress has been achieved in our knowledge of the characteristic features of proton flares and of the active centres capable of producing proton flares. Successful forecasts of proton flare events during the period of the Proton Flare Project give good evidence of this.

The many years' standing problem of the broadening mechanism of Balmer lines in flares has been definitely settled in favour of the Stark effect, at flares projected on the disk. The filamentary structure of flares, first suspected by Suemoto and Hiei, has been proved by several authors. The great interest of solar physicists in flares is well demonstrated by the high number of newly proposed or modified flare theories and many of them have already taken the filamentary structure of flares into account. One has to admire many ingenious ideas contained in these theories but, on the other hand, one cannot escape the feeling that we are still far from being able to understand what the flare phenomenon actually looks like.

Observations of longitudinal magnetic fields in prominences have progressed in the past three years. They indicate that field strengths in quiescent prominences range from about 2 to 10 G, while active prominences and loops are associated with substantially stronger fields. Great attention has been paid to loop systems which imply a conveyance of field into the corona and are a manifestation of the storage in the corona of fast, non-thermal particles. Another problem which has been extensively studied, is the filament activation by active regions. Newly detected characteristic oscillations of 'winking' filaments, sometimes starting tens of minutes before a flare appearance, might be very significant for our understanding the active processes on the Sun.

Analyses of monochromatic solar corona indicate a filamentary structure of coronal condensations, matter in the condensation being largely concentrated in loop systems. A combination of Coronascope II, solar eclipse, and nearly synoptic K-coronameter observations permitted to get a unique series of coronal data covering several solar rotations. In this way, a streamer co-rotating with the chromospheric features could be followed for about two months. June 14, 1966 was the historical date, when on the first time, the Sun was photographed from the surface of the Moon.

The role of gyro-resonance absorption and emission by electrons has become better understood, both with regard to the microwave slowly varying component and to the emission of type IV bursts at cm and dm wavelengths. Progress has also been achieved towards an understanding of the harmonic structure of type II bursts, an agreed-upon mechanism, however, has not yet been accepted. On the other hand, most of the properties of type I noise storms are still unexplained and the question, how to account for elliptical polarization of type III bursts, is not yet satisfactorily answered. Thanks to the great number of single-frequency records, made by many observatories on a regular scheme, it is now possible to derive spectral diagrams for most of the major radio events. On the other hand, there is still a great want of more data on source positions and polarizations of type IV emission.

Direct X-ray spectroheliograms at a variety of wavelengths have verified close correlation of increased X-emission with plage activity; at short wavelengths, beneath ~ 15 Å, the emission arises entirely from centres of activity and seems to be concentrated in small, hot elements embedded in a larger lower temperature region of the coronal condensation. The degree of concentration to active regions as observed by slitless spectra in the XUV wavelengths, also depends markedly on the ionization equilibrium temperature of the emitting ion and seems to be a function of the stage of development of the spot group. It has been agreed that the X-ray emission from active regions as well as many X-ray enhancements associated with flares are of thermal origin. Contradictory conclusions appear, however, as to the height of these emissions in the solar corona, as well as to the mechanism producing possibly non-thermal X-ray bursts. The observation of the solar eclipse in 1966 by means of the Explorer 30 satellite by the Arcetri group has demonstrated the wide applicability of the RTT monitoring system.

The number of papers dealing with observations of solar particles from space vehicles has increased many-fold since the last report. Very important studies were made with the Pioneer 6 space probe; the data indicate the existence of large numbers of filamentary tubes, originating at the Sun but intertwined in interplanetary space. In spite of twisting and intertwining of these filaments, the spiral configuration remains. Cosmic rays are envisioned as constrained to the flux tubes. A number of proton increases was observed aboard several space probes, only partly associated with flares. Some events were even recorded aboard two or more Soviet or American space probes and deep-space satellites. The important role of α-particles in streams of high-energy particles, recognized during the past years, throws some doubt on the terminology of the 'proton' flare events. Nuclei with $Z > 3$ have been observed after major flares on at least four occasions and possibly in some other events, as well. It is not yet clear, however, to what extent the composition of the nuclei reflects the photospheric abundance.

Evidence for solar-flare electrons was also obtained from IMP and Electron satellites and from the Mariner 4 space probe.

A comparison of IMP-1 magnetic field data with solar magnetograph observations has shown that the interplanetary magnetic field is directly tied to and co-rotates with the solar photospheric magnetic fields. During the minimum period of solar activity, since 1962, the interplanetary magnetic field was divided into 2, and since late 1963, into 4 sectors, alternating in direction toward and away from the Sun, and this structure had correspondence to grossly averaged magnetic features in the photosphere. This low-activity structure of the interplanetary space becomes less stable as the solar activity increases.

Summarizing these discoveries, one observes that, generally, two basic features characterize the past period in the research of solar activity: a progressive tendency to discover fine structure in all the studied phenomena and a gradual transformation of our old conception of the interplanetary space into the new one of an extensive and expanding solar atmosphere, directly studied with deep space probes.

2. EQUIPMENT AND METHODS

2.1. *Optical observations*

A new solar research station of the Cambridge Observatory was completed at Rabat (Malta). It is equipped with a large horizontal solar telescope of about 40 meter length with a large Babcock grating and all facilities for photographic, photometric and magnetographic work. At the Observatory of the University of Hawaii four new solar instruments have been installed: A 10-inch aperture (25 cm) Lyot coronagraph which feeds a coudé spectrograph with dispersion 1 or 6Å/mm; a dual coronagraph which is to obtain simultaneously photographs through 2Å interference filters of the corona in the green line and of active prominences in Hα; a moderately large-scale Hα camera which is used to study individual active regions under conditions of good seeing; and a photographic polarimeter for determining Stokes parameters of the radiation in broad spectral bands. The Manned Spacecraft Center installed in 1966 three Hα solar telescopes employing a Lyot-Öhman filter, one on a seventy foot tower at Houston (Texas) and the other two in Carnarvon (Australia) and in the Canary Islands. New solar observatory of the Deutsche Forschungsgemeinschaft near Locarno, equipped for observations of active solar phenomena, was described by Brückner (1964).

The new domeless coudé refractor for solar work on Capri was described by Kiepenheuer (1964*b*). Inner tube contains a 35 cm objective of 15 m focal length and an outer tube protects this first one against wind and rain. Through the polar axis the solar light is guided to a spectrograph. A new solar telescope and spectrograph with 70 cm coelostat and 50 cm objective was also installed at the Kwasan Observatory (Nakai and Kubota 1964). The McMath solar telescope at Kitt Peak was described by Pierce (1964), and the description of an evacuated tower telescope planned for Sacramento Peak Observatory was given by Dunn (1964).

A triple heliograph, which allows to take simultaneously Hα and K line filtergrams together with a photospheric picture was installed at the National Observatory in Athens. At this Observatory also a new automatic solar telescope equipped with Halle Hα filter and TV technique was built. At the Monte Mario Observatory in Rome, regular patrol service has been started in 1964–65 both in the Hα and K lines. A new Halle Hα filter at Irkutsk allows to get automatically Hα filtergrams at 0, ± 0·25, and ± 0·50Å from the line centre (Skomorovsky 1966). The composite filtergrams taken in three wavelengths (0 and ± 0·50Å) in the Hα line at Lockheed were described by Larmore and Ramsey (1964). New equipment, which allow to photograph simultaneously solar disk and solar limb, were described by Michard (1965) and by Carroll (1965). A new space-velocity coronagraph, which allows to get simultaneous photographs of the prominence image and of the Hα line in its spectrum was installed at Ondřejov (Valníček and Kleczek 1964, Valníček *et al.* 1965). The new spectroheliograph of the Catania Observatory, applicable to Hα, Hδ, K and λ4247 lines was described by Fracastoro and Cristaldi (1964). A new electrophotometer for fast recording of the Hα line profiles of limb phenomena was built at the Kiev Observatory of the Academy of Sciences (Gurtovenko and Skorik 1965).

A new Zeiss (Jena) coronagraph was installed at Lomnický Štít in High Tatra Mountains (Lexa 1963). The new coronagraph and spectrograph at Climax was described by Rush and Schnable (1964). Modifications of the Lyot coronagraph, leading to an increase of speed of measurement of the absolute intensities of coronal lines in various coronal regions have been realized at Pic-du-Midi (Demarcq *et al.* 1965). The Astrophysical Observatory Arosa has been equipped in 1965 with a new Zeiss (Oberkochen) coronagraph. It is combined with a powerful grating spectrograph; using a dispersion of 5 Å/mm and a slit width of 0·03 mm, the exposure time for the λ5303 line is one second only. The K-coronameter of the Norikura Corona Station and the method of observation and reduction of the observed results were described by Nagasawa *et al.* (1965). A description of the optical scheme and the main characteristics of a large Lyot-type coronagraph which is being made in U.S.S.R., was given by Nikolsky and Sazanov (1966).

A combined narrow-band filter consisting of 3 Å multilayer filter and the three thickest elements of Lyot-Öhman filter was described by Zirin (1966). Ramsay (1966) gave a description of a new monochromatic filter based on a series of plane-parallel Fabry-Pérot interferometers aligned in a parallel mode. Lyot-Öhman and Šolc filters produced in Czechoslovakia were described by Valníček (1965*a*). Hamana and Suzuki (1966) studied a method of reducing the effect of finite filter pass-band on the intensity measurements of flares. A double image line shifter proposed by Öhman (1966*a*) has been used by Nilsson (1966) for the purpose of determining Doppler velocities of dark and bright surges. Öhman (1966*b*) also made a suggestion for reducing scattered light in sunspot photometry by a special system of two diaphragms and tests have shown that the influence of diffracted light from the circumference of the objective is reduced to a minimum with this device (Kussovsky 1966). Öhman (1966*c*) also proposed other methods for the same purpose. An electronic device for discriminative measurements of sunspot areas was described by Boev *et al.* (1965). Giovanelli (1966*b*) discussed methods and techniques for the observation of sunspots in white light, including discussions of seeing, scattered light, thermal deformation of mirrors and photographic techniques.

2.2. *Magnetic field measurement*

Since the beginning of 1964 considerable effort has gone into the construction of new instrumentation at the 150-foot solar tower telescope at Mt Wilson. A guider and scanning system have been installed which now enable to scan the solar image very accurately in any desired raster pattern. The solar magnetograph has been completely rebuilt, and two spectrum lines can now be used simultaneously. Data are recorded on a magnetic tape recorder for later analysis with a digital computer (Howard 1966). A double magnetograph recording simultaneously magnetic field in two different lines (λ5250 and λ6103, or Hα) also started to work in 1965 at the Crimean Observatory (Severny 1966*a*) and a similar device has also been developed at Nizmir (Moscow), for simultaneous observations in λ5250 and Hβ lines (Zhulin and Mogilevsky 1965*b*, Mogilevsky *et al.* 1965). An earlier description of the electronic scheme of the Crimean magnetograph was published by Nikulin (1964) and further details concerning the magnetograph at Nizmir were described by Iospha and Mogilevsky (1965) and by Ioshpa and Obridko (1965*d*).

A new magnetograph recording all components of the solar magnetic field has been designed at Irkutsk (Kuznetsov *et al.* 1966). The domeless coudé refractor at the German station at

Capri (Kiepenheuer 1964*b*) is combined with a longitudinal and transverse magnetograph with automatic mapping of the field distribution (Deubner 1966). The McMath-Hulbert Observatory has improved its measurements of solar magnetic fields through the addition of a Glan Thompson prism and mica quarter-wave-plate to the optical train of the vacuum spectrograph. A magnetometer for the study of weak longitudinal magnetic fields has been developed by Bhattacharyya at Kodaikanal. A Babcock-type magnetograph has been established in the solar tower on Monte Mario in Rome. At this Observatory also the measurement of sunspot magnetic fields has been modernized and is now carried out by means of a photomultiplier and a study of the Zeeman effect by atomic beam without using high dispersing spectrographs is in progress.

A detailed summary of methods of measurements of solar magnetic fields was presented by Severny (1966*c*). Bruns *et al.* (1965) described a method used at Crimea for measurements of transverse magnetic field. The method of observation of the total vector magnetic field with the Pulkovo Observatory magnetograph was described by Kotljar (1964). The method of simultaneous measurements of solar magnetic fields on two levels in the solar atmosphere was explained by Zhulin (1965) and the selection of proper lines for this purpose was discussed by Dubov (1966*a*) and Severny (1966*a*). Kuklin (1966*b*) described the electro-optical modulator of the solar magnetograph at Irkutsk. The degree of reliability of radial velocities obtained by means of a magnetograph was discussed by Ioshpa and Obridko (1965*b*) and by Ikhsanov (1966) and the influence of seeing on measurements of radial velocities with a magnetograph was investigated by Gopasyuk and Severny (1964). A method for deriving the complete magnetic field from magnetographic measurements of the longitudinal Zeeman effect was proposed by Schmidt (1964, 1965) and modified by Semel (1967). Possible effects of steep field gradients between close spots on results obtained with a scanning magnetograph were discussed by Teske *et al.* (1964). The method of magnetic field measurements at Meudon has been analysed by Semel (1967).

A method of measuring solar magnetic fields by using a birefringent filter with twin transmission bands was proposed by Öhman (1965) and a very similar method actually has been applied in Meudon. A method of the determination of three components of the magnetic field of sunspots by means of a 'lambdameter' was described by Rayrole (1964). The same author (Rayrole 1966) has designed and proven a method for deriving the full magnetic field vector from photographic measurements of the Zeeman displacements of lines observed in various polarization states. The method uses simultaneously two lines from the same multiplet but with different Zeeman patterns, which gives the possibility to determine also the scattered light in spots.

The magnetograph of the High Altitude Observatory at Climax, used for measurements of magnetic fields in prominences using the Hα line was described by Lee *et al.* (1965). Sensitivity of the equipment equals two gauss. Smolkov (1966*a*) has shown that, in principle, it is possible to get information on the coronal magnetic field when applying a sensitive photoelectric method to the λ5303 line.

2.3. *Solar radio astronomy*

New radiotelescopes have been installed at several observatories: 8 mm wavelength at the Crimean Observatory (Efanov and Moiseyev 1965), 2700 MHz at the Dominion Radio Astronomical Observatory in Penticton (Covington and Locke 1965), 2000 MHz at New Delhi (Sarma and Joshi 1965), 930 MHz at Bordeaux (Bernyer *et al.* 1966), 700 MHz at Fleurs, 408 MHz at Nançay, 87·4 MHz in Catania, and 74 MHz solar radio polarimeter in Ottawa (Bhonsle and McNarry 1964*b*). Eight-foot disk antennas for continuous solar observation at 1420, 2700, and 5000 MHz have been installed in 1966 by the Manned Spacecraft Center at Houston, Carnarvon and in the Canary Islands. A method permitting records of very weak microwave bursts was described by Durasova and Yudin (1966).

At Fleurs Observatory, in 1964, additions have been made to the east-west arm of the 21 cm crossed grating interferometer to enable simultaneous operation at 43 cm wavelength. A 16 element 408 MHz array giving a resolving power of 1·6′ in the E–W direction with separation between lobes of 25′ was installed at Nançay (Clavelier 1966). The large radiotelescope completed at this observatory has been used for solar observations at 5000 MHz with a resolving power of 1·2′ × 6·5′. At Toyokawa, the 16 + 2 element compound interferometer for use at 9400 MHz was extended to 32 + 2 elements in 1966, and the maximum resolving power was increased from 0·7′ to 0·35′. A new 32 + 2 element compound interferometer for use at 3750 MHz and a two-element interferometer at 1000 MHz were completed in 1967 (H. Tanaka 1966). A multi-element interferometer for 2700–2900 MHz has been built at Algonquin Radio Observatory (Covington *et al.* 1965). An interferometric method which can easily measure the position, motions and intensity of an isolated active region on the disk was described by Turlo (1965).

The Dapto radio spectrograph, which worked in the frequency range from 5 to 210 MHz has been extended to 2000 MHz (Suzuki *et al.* 1964). A radio spectrograph working in the frequency range from 50 to 210 MHz was completed in 1966 at Ondřejov (Tlamicha 1966). A 20 channel spectrum radiometer operating between 20–120 MHz at a sampling rate of 100 per second with a fibre-optic real time direct recording system has been installed in Ottawa in 1966. The design of a receiver with 60 channels intended for the frequency band 160–320 MHz as a radio spectrograph with high sensitivity and high time resolution, was described by Van Nieuwkoop (1964). A description of the radio spectrograph equipment at Boulder was given by Lee and Warwick (1964).

2.4. *Observations from space vehicles*

Apart from many launchings of balloons carrying equipment for recording high-energy particles, two balloon-borne solar telescopes were launched during the investigated period. The first of them, Coronascope II, was described by Newkirk and Bohlin (1964). In the balloon-borne coronograph the scattered light was suppressed to about 10^{-8} of the mean solar disk brightness. Two successful flights of Coronascope II took place on 3 June and 1 July, 1965. Solar corona was also observed from the Moon on 14 June, 1966, with the Surveyor I TV camera (Newkirk 1967). The second balloon-borne telescope, constructed at the Fraunhofer Institute, was described by Kiepenheuer and Mehltretter (1964). It contains an 0·5 Å Hα Lyot-Öhman filter and a grating spectrograph. Stenflo has started the design of a spectrograph to be used in space research for studying solar magnetic fields in small structure elements of the solar surface. Quite a number of rocket flights were made in U.S.A., U.S.S.R., Great Britain and France for the purpose of obtaining EUV and X-ray spectra and photographs of the Sun. The techniques used for the measurement of X-radiation were reviewed by Boyd (1965).

Only one solar observatory was functioning in orbit during the first year of IQSY. This was the SOLRAD 1964–01 D satellite, launched in January 1964. It was equipped with ionization chambers to cover the ranges 1–8 Å, 8–14 Å, and 44–60 Å, in the RTT system (Kreplin 1965). In 1965, three more solar satellites were launched: OSO–2 (1965–7A), launched on 3 February, which provided a month of continuous observation of the solar X-ray emission and also yielded spectroheliograms and white corona measurements; SOLRAD 1965–16 D, launched on 9 March, which carried the same measurements as the 1964–01 D satellite, but the 8–14 Å detectors were considerably more sensitive; and SOLRAD 1965–93A (Explorer 30), launched on 19 November, which was the most sophisticated satellite in the SOLRAD series. Its digital memory system worked for about one month, but the RTT system provided very useful data on solar X-ray emission within the ranges 0·5–3, 1–8, 1–20, and 8–16 Å until August

1966, when the satellite began a precessional motion. Solar X-ray flux within 2–10 and 8–18 Å was also measured aboard the Electron 2 and 4 satellites (Vasilev 1966).

Many other satellites have provided data on interplanetary magnetic fields, solar wind disturbances and solar high-energy particles. Particularly, these were IMP–1 (launched on 26 November 1963), IMP–3 (29 May 1965), IMP–4 (1 July 1966), OGO–1 (5 September 1964) and Vela 5 and 6 (20 July 1965). The most important information on solar wind disturbances and energetic proton bursts, however, were obtained with deep space probes. Mariner–4, launched on 28 November 1964, provided data on solar particle events for 10 months prior to the Mars fly-by. Soviet space probes Zond–3 (launched on 18 July 1965), Venus–2 (12 November 1965) and Venus–3 (16 November 1965) carried detectors recording 1–5 MeV protons and a gas discharge counter giving information on protons with energy $\gtrsim$ 40 MeV (Vernov *et al.* 1966). Pioneer–6, launched on 16 December 1965, has given valuable data on the anisotropy of solar protons events. Due to this 'high density' of space probes and highly excentric satellites in 1965, some solar wind disturbances and proton events could be recorded aboard several space vehicles in different distances from the Earth.

The network of ground-base RTT monitoring stations has been substantially increased and the observations intensified. As an example, about 700 transits of the Explorer–30 satellite were telemetered in April–August 1966 by the network of the Centre National d'Etudes Spatiales. A solar eclipse was observed by means of the RTT monitoring by the Arcetri group (Landini *et al.* 1966*a*).

3. CYCLIC VARIATIONS OF SOLAR ACTIVITY

3.1. *General contributions*

A monograph, particularly discussing the cyclic variations of the solar activity and the structure and dynamics of the subphotospheric levels was written by Rubashev (1964*a*). Kopecký (1967) summarized our present knowledge on the periodicity of sunspot groups.

Rotational means of the Wolf numbers for 'geophysical' rotation periods 0–1797 (1832–1964) were computed by Schnur and Wagner (1965). Godoli and Allen (1964) summarized and discussed the indices used for describing various characteristics of the solar activity phenomena and the correlation between different indices of solar activity was investigated by Zabza (1964). Autocorrelation of several indices of solar activity was made by Altschuler and Sastry (1965), who compared the years 1937–38, 1947–48, and 1957–58. A power spectrum analysis of time series of several solar indices taking into account only phenomena within ± 1 day distance from the central meridian was made by Shapiro (1965*a*). The result showed a pronounced peak around 27 days and appreciable peaks at the first few harmonics. The mechanism producing the harmonics was also discussed (Shapiro 1965*b*). Eigenson's recurrence indices have been revised by Ringnes (1964*b*).

The east-west asymmetry of sunspots was studied by Dezsö (1965) and by Dezsö and Gerlei (1964*b*). Developing groups prevail on the eastern and declining spots on the western solar hemisphere. On the contrary, Pajdušáková (1964) could not find any east-west asymmetry of sunspots. Xanthakis (1965) discussed the asymmetry in the distribution of the sunspot magnetic field strengths on the northern and southern solar hemispheres and Gleissberg (1964) compared the north-south asymmetry in solar wind (deduced from the geomagnetic activity) and in solar spottedness. Fredga (1965) found evidence of a coupling between the sunspot activity of the two hemispheres in consecutive cycles (12–19) when the latitude distribution was taken into account. She considers this result as a support of Alfvén's magnetohydrodynamic sunspot theory. Godoli and Tagliaferri (1965) pointed out that the increase of maximum sunspot numbers during the past four cycles was not reflected in other phenomena of solar activity and some of them even decreased.

The fact discovered by Trellis (1963) that the axis of sunspot belts is not identical with the axis of the solar rotation was independently confirmed by Kuleshova (1964). The axis deviation amounts to 0°53 according to Trellis and to 0°80 according to Kuleshova.

3.2. *The 11-year solar cycle*

Gnevyshev (1967) has found that each 11-year cycle of solar activity consists of two processes with different physical properties. The variety of shapes of the 11-year curves depends on the way these processes overlap. The existence of such a double 11-year cycle has been shown for coronal observations (Gnevyshev 1965*a*, *b*), sunspots (Antalová and Gnevyshev 1965, Gnevyshev and Antalová 1965), solar radio flux (Gnevyshev 1965*c*) and proton flares (Gnevyshev and Křivský 1966, Křivský and Krüger 1966). Secondary maxima in the spot formation activity connected with the activity development in low-latitude zones were detected by Schegoleva (1965*a*). Vitinsky (1965*c*) has shown that the latitude factor is more important for the indices of solar activity than the factor of the phase of the 11-year cycle. Chistiakov (1965*d*) found five breaks in the 11-year cycle sunspot curve.

Several authors discussed the variations of various aspects of solar activity with the 11-year cycle. Thus Ringnes (1964*c*) studied the life-time and Arroyo (1965) the area distribution of sunspots, Dezsö and Gerlei (1964*a*, 1965) the ratio of penumbral-umbral areas, Xanthakis (1966*c*) different indices of solar activity, Babin *et al.* (1965) the solar supercorona, Tousey *et al.* (1964) the Lyman-alpha profile, Bolshakova (1965) the solar wind velocity, Le Squeren-Malinge (1964*b*) the coronal electron density, Švestka (1966) the proton flare occurrence, and Parmenter (1966) the density of spicules. Giovanelli (1964) has concluded that the frequency of appearance of new spot groups is the prime variable during the cycle. The mutual relations between the differential rotation and the solar cycle were discussed by N.O. Weiss (1965*b*).

The Waldmeier relation between the maximum Wolf number and the time of rise of the cycle were modified and partly applied to the 20th solar cycle by Rubashev (1964*b*), King-Hele (1966), Alexiou and Poulakos (1966) and Xanthakis (1966*b*, *c*). King-Hele has predicted $R_{\max} = 140$ in 1968 and 110 in 1978. According to Xanthakis (1966*b*) the next maximum will not appear before 1968·5. Xanthakis (1966*a*) also discussed the unusually high maxima in the 9th and 19th solar cycles.

Differences between the latitude drift of sunspots on the northern and southern hemispheres were pointed out by Schegoleva (1965*b*) and Gudzenko *et al.* (1965). On the basis of a detailed study of the latitude and longitude drift of sunspots Ramanathan and Natarajan (1965) have concluded that sunspots originate in a layer, which takes part in the differential rotation and consequently must be very close to the photosphere. A modified Babcock theory was used by Kopecký (1966*b*) to an interpretation of the butterfly diagram. The fine structure of this diagram was discussed by the same author (1965*b*, 1966*a*). Tuominen (1965*c*) modified the Babcock theory of the Sun's magnetic field as to the latitude field strength distribution. On the basis of Kopecký's and Tuominen's modifications of the Babcock theory the butterfly diagram was discussed by Godoli (1964*b*, 1965, 1966*b*). Chvojková (1965*a*, 1966*b*) also contributed to the Babcock theory having extended the investigation beyond the latitude of 30°. The drift of sunspots beyond 30° to higher latitudes could be qualitatively explained.

Two zones of coronal activity discovered by Waldmeier in 1940 have been confirmed in 1963 after the beginning of the new spot cycle (Waldmeier 1964). The main zone and the polar zone were well separated from each other by a belt of solar prominences. Hyder (1965*a*) showed that in 1957–58 the reversal of Sun's polar fields was synchronized with the poleward drift of high-latitude filaments. A coincidence of this reversal with the maximum Ca plage activity for each hemisphere was found by Godoli (1964*a*). Although bright surges at the limb should be typical phenomena of the activity centres, observations of Godoli and Mazzucconi

(1967) showed that during 1957–64, 6% of them were polar ($\varphi \geqslant 50°$). They seem to follow the polar faculae activity. Leighton (1964) tried to clarify some aspects in the Babcock's theory, particularly the expansion and migration of unipolar and bipolar magnetic regions and discussed the relation of this process to the 11-year solar cycle. The behaviour of the polar fields over several solar cycles was discussed by Sheeley (1966).

Sunspot minima were investigated by Giovanelli (1964, 1966*a*). On separating spot groups of the old and new cycles, it becomes apparent that the main distinction between different solar minima are the time displacements between the decay- and rise curves. The solar activity during the IQSY period was described in detail by Dodson and Hedeman (1964*d*, 1966*b*) and by Dodson *et al.* (1964, 1965). The last minimum was also discussed by Vitinsky (1965*b*), Chistiakov (1965*a*) and Dinulescu (1965). According to most of these authors the minimum occurred in July 1964 and it was unique by the lowest number of spotless days since the limit of available data in 1818 (Dodson and Hedeman 1966*b*). Bell and Wolbach (1965) have shown that Danjon's equation of the brightness variation of lunar eclipses with the phase of the solar cycle predicts dates of sunspot minima with a high degree of accuracy. The next minimum has been predicted by this method for 1974·9.

3.3. *Other cyclic variations*

A critical summary on the statistics of sunspots, with particular reference to the long-term solar cycle and secular variations of the solar activity was presented by Waldmeier (1966). He concludes that the long-term solar cycle seems to be produced by variations of the relative abundance of spot groups of different life times (in agreement with Ringnes, see below) and areas. According to Dezsö and Kovácz (1965) the ratio of umbra and penumbra area in sunspots shows a long-term variation, the period of which seems to equal eight solar 11-year cycles. Kopecký (1964*a*) proved the existence of the 80-year cycle in the average importance of sunspot groups and discussed some hydromagnetic hypotheses on its interpretation (1964*b*). Schove's auroral numbers were used by Gleissberg (1966) for studying some properties of the 80-year cycles. 38 and 41 years, respectively, have been found as the mean lengths of the period of ascent and descent. Secular variations, distinct from the 11-year period, were found by Ringnes (1963, 1964*b*, 1965) for sunspot groups of various life-times. Groubé (1965) has called attention to the fact that properties of solar cycles before and after 1856 differ in several aspects.

Longer cycles of solar activity were discussed by Golubtsov (1965) on the basis of the data given by Schove. A cycle of 650 years consisting of two 325-year cycles found earlier by Rubashev has been verified. A long-term relation between the solar activity and the Earth's rotation was discussed by Link (1964*a*). A very detailed analysis of indirect records of solar activity in the past 2600 years was made by the same author (Link 1964*b*). According to Link's results, three cyclic variations are clearly recognizable: 11, 80 and 400 years.

3.4. *Physical and statistical interpretations*

General characteristics of the solar activity were tentatively explained by Das (1964), who assumed the existence of a rapidly rotating core of the Sun and outbursts of matter from this core to the surface layers. Gudzenko and Chertoprud (1965) proposed an explanation of solar cyclic activity, according to which a cellular belt originates and gradually dissipates in the convective layer. Separate cells, which detach from the belt and ascend, appear in the form of spot groups. This model was later specified by a detailed analysis of the dissipation of such a belt into cells (Chertoprud 1966). A mechanism of oscillatory instability with a period of the order of ten years has been proposed as another interpretation of the cycle of solar activity by Iroshnikov (1965). The oscillations are due to an interaction of the differential rotation and the magnetic forces. A similar mechanism, with a 22-year period of oscillations, was considered by Krause (1965). A more simplified dynamo theory of the solar magnetic cycle was proposed by Csada (1965). A magneto-convective mechanism for the solar cycles has been suggested by M. L. White (1965). Proshnikov (1965) investigated a possible oscillatory instability of the gas in the region surrounding the surface of the maximum of unperturbed entropy. An oscillatory unstable regime appears in the case when negative dissipation in the convective layer predominates over the positive dissipation in nonconvective layers. The period of the resulting oscillations, however, does not seem to be of interest from the point of view of the known solar cyclicity.

Jakimcowa (1967) has shown that the solar activity fluctuations may be represented by means of a stationary stochastic process. This method makes possible prognoses of solar activity. Chen Biao and In Chun Lin (1965), as well as Paveliev and Pavelieva (1965) tried to find periodic terms in the cyclic variation of the solar activity, which determine the variable heights of the 11-year solar cycles. Some phenomenological properties of the cyclic activity of the Sun were investigated by Gudzenko and Chertoprud (1964) using the cybernetic 'black box' scheme method. Chertoprud and Kotov (1965), Kotov *et al.* (1965) and Gudzenko and Chertoprud (1966) interpreted statistically the variations of solar activity as due to an autonomous generator with one degree of freedom synchronized with a weak periodic force.

Trellis (1966*a*) deduced a formula which gives the height of tide on the Sun caused by planets. The greatest effect is due to Venus and Jupiter and Earth follows as to the importance. A correlation was obtained between the height of tide on the Sun calculated according to this formula and sunspot areas or the numbers of newly born spot groups, respectively (Trellis 1966*b*, *c*). Jose (1965) has pointed out that the variation in the motion of the Sun around the centre of mass of the solar system has a periodicity of 178·7 years, which seems to be related to the cyclic variations of the solar activity. R. M. Wood and K. D. Wood (1965) also tried to explain the 11-year cycle as due to solar motion around the centre of mass of the solar system and found the theoretical period of one solar cycle equal to 11·08 years. Planetary influences on the unstable layers of the Sun have also been considered by Romanchuk (1965*b*) who made some forecasts of solar activity based on the constellations of planets.

4. ACTIVE CENTRES

(The radio, X-ray and corpuscular emission from active regions are reported in Sections 10.2, 11, and 13, respectively.)

4.1. *The structure of active regions*

Morphology of an active region on the Sun was discussed by Kiepenheuer (1966*d*). The chromosphere in active regions seems to be filled by threads of the length of 10^4–10^5 km and thinner than 1″. Sometimes these threads form a loop-like structure (Kiepenheuer 1966*c*). Loop features in all three layers of the solar atmosphere were discussed by Kleczek (1964*d*). Tsap (1965*a*) confirmed that the orientation of fine chromospheric Hα structure is in good agreement with the transverse magnetic fields, which however, is not the case for the orientation of the penumbra filamentary structure observed in integrated light. According to Howard and Harvey (1964), dark fibrils seem to lie perpendicular to isogauss lines of the longitudinal field measured in the photosphere, while the filaments in general lie parallel to these isogauss lines and over the null line of the field. An excellent correlation between the Hα fine structure in an active centre and the longitudinal component of weak and moderately strong magnetic fields was found by Smith and Ramsey (1966), generally in agreement with an earlier Leighton's (1965) result for chromospheric network outside the active regions.

Bumba and Howard (1965*a*, 1966*a*) have found that the supergranular pattern of the solar atmosphere plays a very fundamental role in the development of active regions. New regions are formed in or immediately adjacent to expanding old magnetic fields. The first appearance of the emission of a new active region takes place in the 'intersupergranular' space. This is in agreement with Leighton's (1965) suggestion that the supergranulation currents concentrate the magnetic fields into the chromospheric network.

After reducing solar magnetograms covering a period of seven solar rotations, Bumba *et al.* (1966*b*) have shown that the Sun would appear as a magnetic variable star if viewed near the plane of its equator. Measurements of the integrated solar light in the K_2 line lead to the conclusion that also in the K-line light the Sun can be observed as a variable star (Bumba and Růžičková-Topolová 1967). H and K line profiles in active regions were studied by Paciorek (1965) and Engvold (1966). According to Korobova (1965) the area of spots and the area of plages on the phase of growth of an active region are connected by a linear relation. Similar study for the phase of decline was made by Yilmaz (1964*a*).

Kuznetsov and Stepanov (1966*a*) found motion velocities in local magnetic fields increasing from $-50\ \mathrm{m\,s^{-1}}$ at the photospheric level to $-500\ \mathrm{m\,s^{-1}}$ at $h \simeq 2000$ km (Hβ line) and to $-2\ \mathrm{km\,s^{-1}}$ at $h \simeq 4500$ (K_3 line) and identified them as velocities of the sporadic solar wind. Motions in an old centre of activity at the limb were studied by Zirker (1965). He found larger line-of-sight velocities than for spicules in quiet regions. Kaplan and Petrukhin (1964) tried to interpret peculiar motions of gases observed far from any sunspot group in a region of increased magnetic field.

Parker (1964*e*) has discussed the problem whether the presence of magnetic fields enhances the generation of sound waves. He has shown how the magnetic fields are directly responsible for the enhancement of the chromosphere and corona above plages. Pikelner (1965, 1966) has summarized older ideas of himself and other authors about the appearance of active regions (plages) caused by a 10 to 20% increase in the convection velocity, this increase being due to the fact that a weak magnetic field suppresses small-scale motions and decreases turbulent viscosity. Pikelner and Livshitz (1964) concluded that above active regions the energy is transmitted to the chromosphere by decelerated Alfvén waves, which are transformed in the corona to magneto-sound waves and dissipate. The manner in which the dissipation can occur was investigated by Gold (1964, 1965). Hydromagnetic oscillations in an isothermal atmosphere with a vertical magnetic field were studied by Stepién (1966). The energy flow through an active region was discussed by Kiepenheuer (1966*a*).

The nature of M-regions was studied by Piddington (1964) and Mustel (1966). While Piddington supposes that these are regions on the Sun above which the magnetic field is unusually weak or lies perpendicularly to the geomagnetic equatorial plane, the analysis made by Mustel has shown that M-regions seem to be final, very prolonged 'magnetic-tail' stages of active regions.

4.2. *Magnetic field measurements*

Review papers on solar magnetic fields were presented by Severny (1964*b*, 1965*d*), Howard (1965), Schatzman (1965*c*), Zirker (1965) and von Klüber (1966).

Fine scan magnetographic observations made by several authors (Severny 1964*a*, *b*, 1965*c*, Bumba and Howard 1965*d*, Stenflo 1966) show that what appears with small resolution to be a relatively homogeneous structure (e.g. unipolar regions) breaks down to a complicated multi-polar structure at high resolution, with a complicated demarcation line between polarities and rapid change in orientation of the field vector. The maximum field strength and the number of magnetic elements resolved increases with increasing resolution. The disbalance between N and S fluxes characteristic for weak magnetic regions is also found to be increasing with increasing resolution.

Using the new double magnetograph at Crimea, Severny (1966*a*) observed many facts which are evidence of the very fine structure of solar magnetic fields with the heights in solar atmosphere. He has found appreciable differences in the magnetic field structure of active regions in the photosphere and chromosphere (the Hα line) and even in the photosphere at the levels of λ5250 and λ6103 lines. Particularly the appearance of isolated fields of one sign only at the intermediate level (λ6103), with no fields of opposite sign in their vicinity is difficult to understand. Much work in this way has also been done at Izmiran in Moscow. Hβ measurements of local magnetic fields made it possible to detect isolated fields in the chromosphere, of considerable strength ($\sim$ 150 G), without connection with the photospheric fields (Ioshpa *et al.* 1964, Mogilevsky and Schelting 1966), which strongly indicates a force-free structure of local magnetic fields in the chromosphere. A scheme of permanent generation in active regions of corpuscular streams consisting of discrete plasmoids with quasi force-free magnetic field has been offered (Kalinin and Mogilevsky 1965, Mogilevsky 1966*b*). This hypothesis of force-free fields was criticized by Wallis (1965*b*). Severny (1966*a*) and Ioshpa and Obridko (1966) raised some objections against the use of the Hβ line for measuring the chromospheric field.

Zhulin and Mogilevsky (1965*a*) investigated magnetic field variations in active regions and have concluded that the magnetic fields in plages and sunspots are mutually independent. Bumba and Howard (1965*a*, 1966*a*) have found that the increase of the magnetic flux takes place only during the first few days of the development of an active region. Semel (1967) has studied the 'balance' of magnetic fluxes for various active regions. On the basis of an investigation of the trajectories of individual knots in an active prominence, Rompolt, (1965*a*, *b*) constructed a picture of the magnetic lines of force above the active region.

In fields of intermediate field strength, Bumba and Howard (1965*a*) have found that the magnetic flux of the predominant polarity is concentrated around the boundaries of the supergranules, and the opposite polarity is seen weakly in the centre of each cell. Using the photographic technique of Leighton, Sheeley (1966, 1967) has found that during the development of a bipolar magnetic region the flux density is distributed in successively smaller fragments. Field strength as high as 700 G was detected in some of them. The semiregular pattern of weak magnetic fields in the photosphere has been explained by Bumba and Howard (1965*b*) and by Bumba *et al.* (1966*a*) as the result of the expansion, weakening and stretching by differential rotation of magnetic fields of old active regions and of continuing development of new regions within the pattern. The largest of the complexes of activity, consisting of many active regions, result in formation of very complex features of unipolar magnetic regions. Leighton (1964) interpreted the dispersal and migration of unipolar and bipolar regions as a random-walk, diffusion-like process caused by supergranulation convection currents. All these measurements are generally consistent with the hypothesis that bipolar magnetic regions are the sources of all the flux on the solar surface (Sheeley 1966).

4.3. *Flare activity*

A monograph on the morphology of solar activity was published by Vitinsky (1966). A general review of the different phenomena occurring in solar active regions was presented by de Jager (1965*b*).

Some general characteristics of solar active centres were studied by Vitinsky (1965*a*), who modified the Švestka's earlier classification of active regions, particularly based on their flare activity. A magnetic classification of solar active regions, which characterizes well the production of flares, has been proposed by Martres *et al.* (1966*a*). The probability of flare occurrence in relation to the area of spot groups was discussed by Garczyńska *et al.* (1967).

Characteristics of active regions capable of producing proton flares were described by Avignon *et al.* (1964*a*, 1965, 1966) and by Levitzky (1964, 1965, 1966). Kopecký and Křivský

(1966) have found indications that the occurrence of small sunspot groups in the vicinity of large E and F groups may be the stimulating factor, which gives rise to proton flares in the large groups. The 'repetition centres', which give rise to more than one type IV burst, were studied by Lapointe (1964) and Caroubalos (1964*b*). Strong enhancements of 3·3 mm emission were observed by M. Simon (1965) in regions that later flared. Tanaka and Kakinuma (1964) have found that the 3·2 to 7·5 cm flux ratio of the slowly varying component is greater than unity in most active regions in which proton flares appear. Elliott and Reid (1965) suppose that the class 3 flare on 26 September 1963 did not produce any GLE due to the late phase of development of the associated active region. C. S. Warwick (1965*a*) has found that proton flare regions cluster in certain preferred heliographic longitudes.

Bruzek (1965) studied the evolution of one of the most active regions of the last solar cycle, which appeared in July 1961 and an analysis of flares, magnetic fields and activity in the sunspot group of September 1963 was presented by Zirin and Werner (1967) and by Moreton and Severny (1967). This active centre was also studied by Anastassiadis *et al.* (1964).

5. FACULAE AND PLAGES

Tokuya and Nagasawa (1964) drew attention to the fact that there are systematic differences between the areas of Ca plages as given by various observatories. The foreshortening correction for Ca plages was discussed by Godoli and Monsignori Fossi (1967). The same authors (1966) also performed a research on Ca plage evolution. Maps of Ca plages for the first year of IQSY were published by Godoli (1966*a*). Preferential longitudes in the occurrence of Ca plages were found by Godoli *et al.* (1966).

V. A. Krat (1965*a*) studied the H and K line profiles in the calcium chromospheric faculae. He concludes that calcium faculae cannot be regarded as the tops of photospheric faculae and finds that chromospheric faculae are localized in the lower chromosphere below 1000 km; H_3 and K_3 originate in higher levels in the coldest chromospheric elements with $T_e < 7500$°K. Conditions for Ca II emission in chromospheric formations were discussed by the same author in an earlier paper (V. A. Krat 1964). On the basis of hydrogen and calcium chromospheric lines, cold and hot elements in faculae in various parts of active regions were discussed by Kuznetsov and Stepanov (1966*b*). Transversal and longitudinal magnetic fields of ~ 200 G were found in a bright plage by Stepanov and Grigorev (1966). Regions with a purely longitudinal field usually are very small. The authors suppose that the increase of such an area is the necessary condition for a spot occurrence in the plage. Tsap (1965*b*) has found that the brightness of flocculi in the K-line increases with the strength of all components of the magnetic field. The brightness does not increase after some maximum brightness is reached. The corresponding limiting field strength is different for various plages and even for different places of one plage. Livshitz (1965) has shown that the increase of the emission flux in the faculae can be well explained by an increase of the velocity of convection in the sub-photospheric layers by 30%.

The depth distribution of the temperature in faculae was investigated by several authors. Kuzminykh (1964*a*, *b*) and Kozhevnikov and Kuzminykh (1964) worked out a facula model using data on the continuous spectrum of the faculae. Polonsky (1965, 1966) studied infrared lines of the molecule CO and deduced the rotation temperature in one facula, very close to the temperature of the neighbouring photosphere in the uppermost layers. Curves of growth were constructed for four faculae by Voyhanskaya (1966). An inhomogeneous facula model made up of hot facular granules embedded in regions with physical conditions identical to those in the normal undisturbed photosphere has been suggested by Withbroe (1967). Bachmann (1967) discussed Hα, Hβ, H and K-line profiles in plages and evaluated the excitation temperature in them.

The He λ10 830 line profiles in plages were studied by Gulyaev (1964) and by Namba (1965*a*). The non-thermal velocity in plages was found by Namba lower than in the quiet chromosphere. This fact has not been confirmed by V. A. Krat (1965*a*), who found the non-thermal velocity in calcium plages equal to 15 km s^{-1}. Voyhanskaya (1965) determined the non-thermal velocity gradient above calcium plages, 7 m s^{-1} km^{-1}. A broadening of the cores of D Na and b Mg lines in spectra of faculae in comparison with the photosphere was observed by Teplitzkaya and Effendyeva (1966). They interpret it as due to an increase of the non-thermal velocity in faculae, by the factor of about 2. Orrall (1966) investigated vertical velocity fluctuations in weak plages as inferred from observed wavelength displacements of the K line core. Much longer periods of these fluctuations were found in bright calcium flocculi and particularly in one weak plage than in the undisturbed chromosphere. On the other hand, a similar study made in the photospheric λ3931 Fe I line did not show any difference (Orrall 1965*a*).

Observation of the hydrogen λ21 655 Å and λ12 818 Å lines in a facula were described by Mitropolskaya (1966). An upper limit of the ratio $N(\mathrm{He}^3)/(N(\mathrm{He}^4)$ in plages equal to 10^{-2} was determined by Namba (1965*b*).

A negative correlation between the mean annual numbers of polar faculae and the sunspot relative numbers was found by Y. Tanaka (1964) and by Sheeley (1964, 1966). Sheeley concludes that the number of polar faculae can be considered for a measure of the magnetic field in the polar regions.

6. SUNSPOTS

6.1. *General problems*

A general discussion of the sunspot phenomenon was presented by Kiepenheuer (1966*a*) and review papers on the structure of sunspots and solar magnetodynamic theories were given by de Jager (1966) and Ferraro (1966). Reviews of statistics and evolution of sunspots were presented by Waldmeier (1966) and Xanthakis (1966*e*).

An extension of the Waldmeier classification of sunspot groups has been proposed by Künzel (1964) in order to describe the trend of the group development. This new classification takes into account development indices, the frequency of flares, plage areas and magnetic classification. According to Martres (1964, 1966), γ and $\beta\gamma$ regions are formed as products of an accidental superposition of normal sunspot groups. Dezsö (1964) classified evolutionary phases of sunspots by variations in the umbral and penumbral areas of single spots and spot groups. According to Dezsö and Gerlei (1964*a*), the spot and group development can be predicted from the ratio of penumbral-umbral areas. The lifetimes and some other basic characteristics of sunspot groups were discussed by Ringnes (1963, 1964*a*, *b*, 1965) and by Kopecký and Suda (1965). A large sunspot group of 8–18 June 1963, was described by Belorizky (1964).

Kozhevnikov (1964*a*) has shown that the area of a spot group increases in the same manner as the area of a section of a sphere rising in a liquid. The ascent velocity is proportional to the magnetic field strength of the group. From this point of view, Kozhevnikov (1964*b*, 1965*a*) also discussed some geometrical characteristics of sunspot groups. Some of them indicate that the magnetic field is concentrated in the lower parts of the convective zone and is carried upward by convective currents in the initial phase of the solar cycle (Kozhevnikov 1965*b*). Vitinsky and Ihsanov (1964*a*, Vitinsky 1965*a*) have shown that the alteration of the area of a sunspot group before the maximum of development cannot be described by one law, and three types of sunspot groups have been distinguished according to the rate of the area increase.

The proper motion of large bipolar sunspot groups was investigated by Yilmaz (1964*b*) with the result that the follower spot had a larger eastward proper motion than the leader spot. On the other hand, this divergent motion depends on the state of evolution (Dezsö *et al.* 1964), the average velocity of developing spots being higher than that of declining ones. Vitinsky and Ihsanov (1964*b*) have shown that the change of distance between the main spots can be explained as the raising of a magnetic tube to the solar surface, with an average velocity of ~ 115 m s^{-1}. It has further been shown by Ward (1966) that the average longitudinal motion of a sunspot is an inverse function of the spot size and that the motion decreases in the proportion in which the group develops in area (and on this basis, the solar-rotation rate for sunspots has been corrected). Bumba (1964*b*) found two types of motion of small sunspots in the group relatively to the main spot: shifts in spirals around the main spot with velocities approaching 50 m s^{-1} and motions from East to West usually in the following part of the group with velocities of 100–200 m s^{-1}. Both types of motion take place practically parallel to isogausslines of the magnetic field. Gopasyuk and Moreton (1967) have found that the direction of relative motions of sunspots in an active group tends to coincide with that of transversal field.

Jakimiec (1964*b*) has deduced from micrometric measurements that single spots are markedly elongated in the direction parallel to the equator and the same tendency is indicated in spots of bipolar groups, but only during the growth period. Menzel and Moreton (1963) compared stereoscopically photographs taken in 6-hour intervals and clearly observed depressions in sunspots and in their surroundings.

High definition photographs obtained by Stratoscope I have shown many tiny bright dots in the umbra (Danielson 1964, 1966). The diameter is 300 km or less and the lifetime is of the order of 0·5 hour. Bumba (1965*b*) described the process of penumbra formation and disintegration as well as the decrease of umbra on the basis of high resolution photographs. He also studied the development of light bridges from photospheric granulation. Korobova (1966) has shown that one may distinguish three types of photospheric bridges in sunspots. The fine structure of sunspots has also been discussed by Rösch (1966) including a detailed study of umbral granuli. Aly and Galal (1967) studied details in the sunspot structure profitting by the suppressed scattered photospheric light during a solar eclipse.

The relationship of regular sunspots to supergranular cells was demonstrated statistically and on good quality photographs by Bumba (1965*a*). These photographs show light bridges as prolongation of facular network in sunspots. The sudden formation of penumbra appears as the interaction between the spot magnetic field and the field facular network cell. New small sunspots arise always from the peripheries of supergranular cells (Bumba and Howard 1966*a*). Two ways, in which sunspots can be formed directly as the result of the circulation in the supergranulation, have been suggested by G. W. Simon and Leighton (1964). The same authors conclude that the gradual disintegration of sunspots may be due to the 'erosion' of the penumbral boundaries by the large cell currents. According to Leighton (1964), the relative compactness of *p* spots is due to the fact that the lines of force of *p* spots are more tightly twisted and hence offer more resistance toward being 'sliced away' by the supergranulation currents.

The influence of false light in sunspots produced by image motions was discussed by Birkle and Mattig (1965), who calculated intensity profiles in dependence of the diffusion constant. The same influence was studied using photoelectric and photographic observations. A proposal has been made to approximate the scattering function by a sum of two Gaussian functions. Some further information on the atmospheric turbulence were given by Makita and Morimoto (1964). The influence of scattered light on sunspot observations was discussed by Zwaan (1965*a*). Using observations of photospheric Fe II lines fictitiously observed in sunspots he finds that the spot spectrum contains 60% photospheric and 40% umbral light. He also discussed the influence of stray light on the curves of growth.

Bright rings around sunspots were discussed by Chistiakov (1964) and by Kasinsky (1964*a*). Photometric measurements show that the increase of brightness in the ring is due to the increase of the area covered by the granules (Chistiakov 1965*c*) and that the maximum brightness occurs around spots with 30 000 km diameter (Kasinsky 1964*b*). This suggests that sunspots might be identified with supergranuli with strong magnetic fields in their centres. Kasinsky (1964*c*, 1965) and Surkov (1966*a*) also discussed heating mechanisms of bright rings and Kasinsky (1966) found a correlation between the magnetic field variations and the brightness intensity in the rings.

6.2. *Sunspot magnetic fields*

Review papers on the measurements and the structure of the sunspot magnetic fields were given by Severny (1964*b*), von Klüber (1966), Evans (1966) and Jäger (1966).

The magnetic field of unipolar sunspots has been studied extensively by Severny (1965*b*) with the magnetograph of the Crimean Astrophysical Observatory. The appearance of strong transverse fields inside spots is noted again and the run of the field strength and the inclination of the line of force with distance from the spot centre has been analysed. In the penumbra and outside the spot the field is mainly transversal. The variation of the magnetic field strength with distance is similar to that of a dipole submerged beneath the photosphere as has also been found by Ioshpa and Obridko (1965*a*). Severny (1965*b*) paid special attention to the investigation of the system of vertical electric currents in unipolar spots. Polarization measurements with the magnetograph are inconsistent with the transversal field measurements by a polarization detector in a wide spectral region as done by Leroy (Severny 1964*c*). The rapid rotation of the transverse field-strength components leads to the presence of strong vertical currents. From measurements in different lines, Severny (1965*a*, *c*) has found that the rotation might be 80° over a depth difference of 100 km and the existence of twisted field is possible. On the other hand, the appearance of small regions with transverse fields inside sunspots is associated with the occurrence of a characteristic fine structure emission. Examination of high resolution spectra of polarization of sunspots, made by Steshenko (1966) showed that magnetic field of small ($\leqslant 2''$) pores never falls below 1000 G. In one case the magnetic field of ~ 5000 G has been found in a small ($\sim 2''$) area inside a sunspot. Beckers and Schröter (1966) also found isolated points ($< 2''$) outside the spots with strong magnetic fields, ~ 1200 G. They conclude that these magnetic knots fall in dark intergranular space but are clearly distinct from ordinary pores. Sheeley (1966) has found that the source flux of sunspot groups increases linearly with the group size. During the decline phase the flux density is distributed in successively smaller fragments and field strength as high as 700 G was detected in some of them.

First observations of sunspots with the new Capri vector-magnetograph show that in the penumbra the inclination of the magnetic field vector is of the order of 45° and that the central component of a Zeeman triplet is hardly linearly polarized but mainly circular (Deubner 1967). Rayrole (1966) and Semel (1967) investigated the colinearity between the field vector and the gas motion. The motion tends in all cases to be more horizontal than the field. Gopasyuk's (1966*b*) comparison of radial velocities and magnetic fields for bipolar groups has shown that during the stage of development of the group, gases are flowing down inside sunspot at both chromospheric and photospheric levels. According to Gopasyuk (1965*a*), irregular rotation of spots leading to the winding of the magnetic field in a direction opposite to that of the spot rotation is sometimes observed. It leads to a sausage instability of the plasma and in consequence of it to the increase of the frequency in the appearance of surges.

Photographic magnetic field measurements were composed to isogausslines in one sunspot group by Teske *et al.* (1964). The usual picture was obtained but the scanning by photographic procedure with 210 points was too rough. Supplementary data to Nishi's earlier measurements of the orientation of the sunspot magnetic fields were presented by Nishi and Unno (1965). Variations of the sunspot magnetic field as high as 900 G during one day and even as high as 800 G in the course of several hours were observed by Künzel (1967) in some sunspots. Kuklin (1964*b*) found that sometimes magnetic fields of sunspots were rapidly changing although the other active processes were absent.

Magnetic field distribution in three different levels of the solar atmosphere for geophysically active and inactive sunspot groups was compared and discussed by Bumba (1964*a*). From an analysis of the photospheric magnetic field structure and surge trajectories Gopasyuk (1965*b*) concludes that in the corona the spot magnetic field has an azimuthal component which does not depend on the rotation of the spot at photospheric level and the magnetic field decreases more slowly in the corona than in the case of a dipole field. The spot fields are closing in the corona, even in the case when there are large spots between them. From measurements of the chromospheric magnetic field in the Hα line, V. A. Krat (1965*b*) has found that the sunspot magnetic field in the chromosphere is usually greatly displaced from the position of the sunspot in the photosphere; the values of the displacement range up to 17″. It seems, therefore, that the magnetic field of sunspots penetrates into the chromosphere in curved streams of matter. The mean gradient of the magnetic field in the low chromosphere above sunspots was found as 1·2 G km^{-1} (Vyalshin and Krat 1965). On the basis of type IV burst observations, Sakurai (1964) has concluded that sunspot magnetic fields consist of bipolar fields tilted westward.

Godovnikov and Smirnova (1965) made an attempt to compute the sunspot magnetic field by means of elongated magnetic tubes. Kuklin (1964*a*) has shown that the magnetic field of some sunspots can be approximated by an axial force-free field. Mogilevsky (1966*b*) discussed the general properties of force-free magnetic fields and proved the general theorem that isolated magnetic plasma acquires always a force-free magnetic field. Molodensky (1966) described a method of computing the magnetic field in the chromosphere above an axial-symmetrical sunspot on the basis of magnetometer measurements. Zhugzhda (1966) has proposed models of potential fields fur sunspots, by which some peculiarities of spot magnetic fields can be explained. Schatzman (1965*a*) discussed some consequencies of the model of a force-free field in sunspots for the character of fibres seen in Hα spectroheliograms.

6.3. *Motions inside sunspots*

From the study of weak Fraunhofer lines in 62 different sunspots the velocity field has been derived by Maltby (1964). An upper limit of 0·15 km s^{-1} is found for the vertical velocity component and a comparison between observed and calculated line profiles shows a strong velocity change with optical depth. An angle less than 6° with the horizontal plane in the outer part of the penumbra may satisfy the observations as well as the equation of continuity. At the outer limit of the penumbra the velocity falls abruptly to zero (Brekke and Maltby, 1963). At the Kodaikanal Observatory the Evershed effect was studied with Zeeman insensitive lines (Bhatnagar 1964, 1966). The mean velocity gradient was found to be 4 m s^{-1} km^{-1} in depth. Besides the well-known radial velocity a small vertical downward component (0·3 km s^{-1}) in the penumbra was found. Darker penumbral regions show larger equivalent widths in the lines than bright regions. Highly resolved spectra with brightness and sight-line velocity variations and the comparison of lines with different temperature sensitivity lead Beckers (1966) to the picture that the bright penumbral filaments are stationary and the dark regions are moving. This, however, is in contradiction with the results obtained by Schröter (1965*a*, 1966*a*), who studied the centre-to-limb variation of the Evershed flow in one sunspot in weak and strong lines and determined the velocity and angles in dependence of the position in the spot. He concludes that the Evershed effect is produced by streaming in the penumbral fine structure: in the bright structure we have the outstreaming and in the dark channels the in-streaming material. The 'resolved' velocities are about 6 km s^{-1}. The downward motion of the order of 0·3 km s^{-1} is not real, due to a relativistic shift of the photospheric comparison lines. Schröter (1965*b*) estimated the temperature difference between the bright and dark features to 700°. The net flux of kinetic energy is roughly equal to the radiation flux deficit in the spot.

The fine structure of radial velocity distribution in line discontinuities in the Evershed effect was studied by Bumba (1965*c*). Observations at the Kitt Peak Observatory (Bumba 1966) show the absence of the normal Evershed effect in small and young sunspots. Downward motions with velocities up to 6 km s^{-1} in weak lines and up to 14 km s^{-1} in Na D lines have been found. Berdichevskaya (1964) considered the Evershed effect as an outflow of matter in response to a horizontal pressure gradient established between the spot and the surrounding photosphere. The depth-dependence of the velocity corresponds to St John's picture. The rates of outflow from subphotospheric layers are estimated and lead to the low temperature of sunspots. Gopasyuk (1966*a*) has found that the magnetic axis of the spot and the normal to the plane of velocity vectors of the spot coincide and are inclined by 7°–8° to the east of the normal to the solar surface. The difficulties in explaining the peculiarities of the Evershed effect can be overcome by assuming that the magnetic field rises to the surface of the Sun during all the time of existence of the spot.

6.4. *Physical state of sunspots*

Spectroscopic observations of sunspots were reviewed and physical conditions in a standard sunspot were summarized by Van't Veer (1966*a*). Rödberg (1966) measured the intensity ratio between spot and photosphere and its centre-to-limb variation in three wavelength regions with a pinhole camera and found a very good agreement with earlier Makita's and Morimoto's observations. Similar measurements were also made by Surkov (1966*b*). The intensity ratio between spot and photosphere in the $H\alpha$ line, the equivalent width of some Fraunhofer lines and the colour temperature in a spot were determined by Bergsjö (1963).

Zemanek and Stefanov (1964*a*) constructed a curve of growth for Fe I lines in the spectrum of a large spot, taking into account magnetic strengthening. The results were compared with the curve of growth constructed for the same spot from Ti I lines (Zemanek and Stefanov (1964*b*) and for another spot from Fe I lines (Zemanek and Stefanov 1966*a*). Results from three spots lead to the mean excitation temperature of 3900°K and the velocity of turbulence 3·0 km s^{-1} (Zemanek and Stefanov 1966*b*). Olijnyk's (1965, 1966) calculation of equivalent widths shows that magnetic strengthening of the different Fe I lines is from 3% to 10%. A photometry of the continuous spectrum made by Stefanov and Zemanek (1965, 1966) shows that the development of a spot leads to an increase of the brightness in the short-wave region by $\sim 1{\cdot}5$ times. Stepanyan (1966) has found that during the development of a spot the difference of brightness temperature and excitation temperature at $\lambda 6250$Å decreases and, at the moment of the maximum spot area and minimum temperature, this difference is almost vanishing.

A report on the existence of molecular lines in the spot spectra has been given by Moore-Sitterly (1966). Lines of CaH, SiH, TiO and ZrO are present only in the spot spectra, not on the solar disk. Intensity measurements of TiO lines in the spectral region $\lambda > 7054$Å on Kitt Peak and Mt Wilson plates have been carried out by Hitchcock (1965). The slope of the straight line between intensity and rotational quantum number corresponds to a sunspot temperature lower than 1000°K. Some arguments against this very low spot temperature were brought into discussion by Schadee (1966) who showed that a temperature of about 3600 °K was also in agreement with the observations.

The possibility of utilizing sunspot spectra for the determination of elements on the Sun has been discussed by Dubov and Khromova (1964), the main problem being the scattered light. The Li line $\lambda 6103{\cdot}6$Å was identified, with $4{\cdot}6 + 2{\cdot}5$ mÅ equivalent width. The lithium abundance in sunspots was found 7·5 times higher than in the quiet photosphere (Dubov 1964). Schmahl and Schröter (1965) redetermined the lithium abundance and the isotope ratio Li^6/Li^7 using the $\lambda 6708$Å contour of four sunspot spectra obtained by Stumpff. They found $1{\cdot}0 \times 10^{11} < H/Li < 2{\cdot}3 \times 10^{11}$ and $Li^6/Li^7 \simeq 0{\cdot}05$.

The contours of the central part of the H and K lines at different points in one sunspot and its surroundings were determined by Paciorek (1965). The profiles on the two sides of the spot were quite different and the maximum single peak of emission did not lie above the umbra. The comparison between the observed and the theoretical profiles led to a turbulent velocity of 7·9 km s^{-1} in the spot chromosphere. From halfwidth measurements of the K_3 peak in spot spectra turbulent velocities of about 15 km s^{-1} were obtained by Mattig (1966*b*). The absorption D_3 line in the penumbra of one spot was discussed by T. V. Krat (1965).

Equivalent widths of 148 neutral and ionized lines and profiles of the Balmer lines Hα–Hδ have been determined from two concave spectra of one spot by Fricke and Elsässer (1965). The amount of scattered light was derived from the wings of Balmer lines. The variation of temperature and pressure with optical and geometrical depth was deduced; in the spot umbra a remarkably lower gas pressure was found than in the photosphere at the same geometrical depth. Therefore, deviations from hydrostatic equilibrium must exist in the sunspot. Zwaan (1965*b*) discussed the determination of a sunspot model and determined equivalent widths of neutral and ionized lines. A new method suggested by him yields the amount of stray light directly from the spectroscopic measurement. A model was constructed. In contradiction to Fricke and Elsässer, however, Zwaan (1965*b*, 1966) has found that the spot is in hydrostatic equilibrium; models which deviate from hydrostatic equilibrium cannot explain the observed equivalent widths. Zwaan suspects that sub-hydrostatic pressures obtained by other authors, have been due to unproperly corrected stray light. According to Zwaan (1965*b*) there is no dependence of the physical conditions in the umbra on its area, perhaps with the exception of pores and very small spots. On the other hand, Van't Veer (1965) suspects that the gas pressure is lower for larger spots. Furthermore, Zwaan (1965*b*) discussed the sunspot as a stable structure in the solar 'mantle' taking magnetic forces and the Wilson effect into account. A new determination of the gas pressure in the spot has been carried out by Van't Veer-Menneret and Van't Veer (1965), with the result that the gas pressure is about the same or slightly lower than in the photosphere at the same level. The same problem was discussed once more by Van't Veer (1966*b*) with a new statistical method which makes it possible not only to find the best model but also to estimate the validity of the method. The obtained gas pressure is similar to the results of the earlier paper. This method was also applied by Van't Veer (1966*c*) to the Mt Wilson sunspot No. 11 730 and the results were compared with some other recent models.

On the basis of spot photographs showing the Wilson effect, Wilson (1965, 1966*a*) has derived that the absorption coefficient in the umbra is between one or two orders of magnitude less than that in the photosphere. A ratio of one order of magnitude is not inconsistent with the assumption of radiative equilibrium in the umbra. Jensen and Maltby (1965) calculated the optical radius of a sunspot as a function of the vertical optical depth. It is pointed out that the vertical temperature distribution cannot be deduced without taking into account the finite size of the spot. The results indicate that the umbra is about as opaque as the photosphere. Mattig (1967) investigated the same problem of the transparency or the geometrical height-scale from sunspot spectra near the limb. From the geometrical height difference between the origin of the line centre of different lines and the continuum he has found that the spot height scale is of the same order as that of the photosphere. Buslavsky (1966) solved the transfer problem for a cylindrical sunspot taking into account the flux of radiation through the side walls. The temperature distribution in this case depends on the radius of the spot and on the ratio of the absorption coefficient in the sunspot centre to that in the photosphere. Makita (1966) discussed the non-existence of a homogeneous sunspot model and proposed again an umbral model consisting of hot and cold elements. A tentative analysis gives the hot components the flux fraction of 0·5 and space fraction of 0·1. Stankiewicz (1966) studied the relation between the magnetic field strength and the temperature in the sunspot. The temperature difference was found proportional to H^2.

6.5. *Theory*

Hydromagnetic stability calculations which are applicable to sunspots and some recent theoretical sunspot models were summarized by Danielson (1965). Deinzer (1965, 1966) has constructed theoretical sunspot models in magnetohydrostatic equilibrium by assuming that a magnetic field in the hydrogen convection zone inhibits the convective energy transport. The system of differential equations was solved numerically. The results agree with observations to within 50%, the maximum possible field strength at the surface is about 5000 G. Some remarks on this theory have been presented by Wilson (1966*b*), who points out that it is necessary to take into account better values of the sunspot structure in the visible layers. Inhibition of the convective energy transport was also discussed by Chitre (1963). He shows that it is impossible to obtain a reasonable sunspot model assuming a complete suppression of convection. The magnetohydrostatic equilibrium has also been discussed by Jakimiec (1965) and by Jakimiec and Zabza (1965, 1966). With the assumption of a short scale spot model and a depth depression of about 1000 km an equilibrium is possible but not without difficulties; the non-twisted magnetic field is able to balance the pressure difference of about 10^6 dyn/cm^2. In an earlier paper, Jakimiec (1964*a*) presented a sunspot model for Michard's 'typical spot'. The spot was found to be a depression in the photosphere and a medium with the density and transparency nearly the same as in the photosphere.

Oster (1964) proposed a sunspot magnetic field model, in which a single spot corresponds to the end-field of a solenoid approximated by the field of a single current loop. De Jager (1964*b*) assumes that the magnetic field in a sunspot is constant with depth and compares this field with the equipartition magnetic field, which has an energy density equal to the convective energy density in the undisturbed Sun. He finds that below 10^4 km, the tension in the lines of force in a 3000 G sunspot is no longer sufficient to prevent them from being turned over by the convective buoyancy forces. Thus below 10^4 km, the magnetic lines of force are very twisted and disordered in this model. Makarov (1964) made an attempt to connect in one system the magnetic field strength in umbra of a sunspot, the area of umbra and the depth of umbra.

Some observational and theoretical aspects of the dynamics of the evolution in the fine structure of sunspots were discussed by Bumba *et al.* (1966*c*) in relation to the magnetic field structure. It has been shown that neither a pure magnetic field diffusion nor a pure transport of lines-of-force can explain the sunspot development. A scheme of interrelation of turbulent elements of the convection zone and the magnetic tube of the spot was suggested by Chistiakov (1965*b*) as an explanation of the filamentary structure of the penumbra. Tuominen (1964, 1965*a*, 1966) has shown that large horizontal whirls connected with the differential rotation may be created in the photospheric and subphotospheric layers of the Sun. These whirls explain the high magnetic fields as well as the observed movements of individual spots. The relationship of the observed local magnetic fields to convection in the Sun was considered by N. O. Weiss (1964, 1965*a*). Arguments in support of the outward transport of magnetic fields of spots and bipolar regions into the corona were presented by Romanchuk (1965*a*).

A possible mode of nonradiative transport, that of Alfvén waves, was examined by Musman (1965). He has concluded that it is not likely that these waves contribute substantially to the energy transport in sunspots. Hydromagnetic waves in a nonisentropic medium in the presence of a gravitational field were discussed by Getling (1965). Such conditions can occur in the convective zone beneath sunspots. The generation of magnetohydrodynamic waves in sunspots has also been discussed by Marik (1966). The Alfvén wave flux is found higher above the spot than the flux outside spots in active regions, by one order of magnitude.

The perturbing effect of static magnetic fields on the normal distribution of pressure, temperature and density in the solar atmosphere was discussed by Menzel and Shore (1966). The theory was applied to sunspots taking velocity fields into account. Menzel (1964) has also shown that magnetohydrodynamic flow in a force-free medium leads to a form of Bernouilli's theorem: a hot gas flowing at slow speeds along magnetic lines of force, is greatly accelerated and undergoes rapid cooling as it encounters a strong magnetic field. The possible application of this phenomenon to sunspots is evident. Clark (1965) presented some magnetohydrodynamic equations with exact solutions, which might be applied to conditions to be expected in sunspots.

A new discussion of the electric conductivity leads to the conclusion that in the visible layer of sunspots the conductivity is only of the order 10^8–10^9 (Schröter 1966*b*). This value is more than two orders of magnitude lower than assumed before. The consequences are an anisotropic conductivity and a short decay time comparable with the observed sunspot lifetime. A new very careful calculation of the conductivity with different sunspot models and different magnetic field configurations in dependence of the optical depth, carried out by Kopecký and Kuklin (1966*a*), however, leads again to a decay time longer than that obtained by Schröter. A simplified method of computing the electric conductivity in sunspots has been proposed by Kopecký (1966*c*). Tables of electric conductivity in various models of sunspots are presented by Kuklin (1966*a*). Kopecký and Kuklin (1966*b*) also computed the electrostatic field strength for different depths and phenomena in the solar atmosphere. In sunspots, they get 10^{-12} to 10^{-10} cgse.

Obridko (1965*b*) solved the transfer equation for a spectral line with a split upper level in the magnetic field. The first approximation was compared with the Unno solution and quite large discrepancy at the line centre was found. The derived resonance scattering matrix in a magnetic field differs from the absorption matrix (Obridko 1965*a*). Results of numerical computations of the line formation were given by Rachkovsky (1965). For the lines with a non-split upper level true absorption and radiative scattering were taken into account. Very large discordances were noted between the Unno theory and that of the author. Later on, Rachkovsky (1966) has solved the most general transfer problem in case of arbitrary splitting of both quantum levels producing the spectral line in a homogeneous magnetic field. Kats' and Stepanov's (1966) numerical calculations of the intensity profiles for different solutions of the equation of transfer show that especially for magnetic field strength larger than 1500 G the exact solutions of Rachkovsky must be used. A review paper about the line formation in a magnetic field was presented by Mattig (1966*a*). Here, a solution of the equation of transfer with true absorption was given for the special case that the absorption coefficient was composed of a depth- and wavelength-dependent factor.

7. SOLAR FLARES

(Radio, X-ray and particle emission from solar flares are reported in sections 10, 11, and 12, respectively.)

7.1. *General problems*

Review papers on optical observations of solar flares were presented by Byrne *et al.* (1964), Ellison and Reid (1964), H. J. Smith (1964), de Jager (1965*e*), Zirin (1965*b*) and Švestka (1966*a*). The kinematics of flares, with a particular emphasis on explosive-type flares, was reviewed by Moreton (1965*c*). The energy and mass problem of flares was discussed by Bruzek (1966*b*).

The influence of the intermittent pattern of periods of observation on the number of discovered flares of different duration was studied by C. S. Warwick (1965*b*). Some observational and physical aspects of the effective Hα line-width measured with spectrohelioscope were discussed by Fritzová-Švestková (1964*a*, *b*). C. S. Warwick (1964) tried to obtain values of flare importance that would be free from systematic errors, applying approximate corrections to different observatories. A law of foreshortening of the apparent flare area has been deduced by Miyazawa *et al.* (1966). Zirin (1965*c*) and Akinyan (1965) tried to divide solar flares in several morphological classes. Isophotes of flares have been studied by Dizer (1967). A photometric and morphological study of 132 flares observed during IGY was presented by Michard *et al.* (1964). Besides other results, the authors have verified that flares covering umbrae are very active in producing microwave radiation and SID's. Dodson and Hedeman (1964*b*) reviewed the problem of differentiation of flares with respect to SID's and pointed out the influence of inhomogeneities in the set of observed data on any investigation of problems of this kind. They have concluded that the relatively important flares without any associated SID tend to consist of many small parts, primarily far from major spots and are not associated with any significant microwave radiation. Mitra (1964) described the effect of a sudden increase in long-wave field intensity and considered it for the best indirect method of observation of flares. This conclusion was opposed by J. H. Reid (1965). Short periodic regularities in the occurrence of solar flares have been suspected by Paghis (1964) and by Tifrea (1965). Obashev (1966) has found that the area of a flare is proportional to its lifetime t, and the total energy of a flare in the optical region is proportional to $t^{5/2}$.

The series of large flares which occurred in July 1961 was discussed by Bruzek (1965), who also constructed a typical 'complete' large flare event. Detailed analysis of flares in the sunspot group of September 1963 was presented by Zirin and Werner (1967). They have found that most flares are homologous and some are triggered by disturbances elsewhere in the region. Observations of two active events on the Sun in the morning of 22 June, 1962 were described by Ballario and Tagliaferri (1964). Dodson and Hedeman (1965, 1966*a*) have suggested that some flares which appear in one active region within two hours, may be actually two phases of one complex flare phenomenon, while the late phase of major flares may be a development of phenomena initiated during the early phase of the complex event. Major homologous flares can repeat in less than five hours. McKenna (1965*c*) pointed out that a number of flares which appeared in the large group of July 1959 consisted of brightenings of apparently the same portions of the calcium plage. The relative structure of the chromospheric network remained fairly unchanged in spite of the great variations in the underlying sunspot pattern. According to Bumba and Howard (1965*c*), the flare development in each of its stages is in a close relation to the pre-existing calcium network.

Hallam (1964) reported on observations of flares in the hydrogen Lyman-alpha line aboard OSO-1. The Lyman-alpha contrast of the flare to the surrounding background is estimated at 5–150.

7.2. *Association of flares with magnetic fields and sunspots*

Magnetic observations relating to solar flares were reviewed by Howard (1964) and by Severny (1964*a*). Generally the occurrence of a flare results in the decrease of the magnetic gradients in the vicinity of the neutral points and this effect is most pronounced for proton flares. Godovnikov *et al.* (1964) have found indications of this effect in smaller flares as well. A simplification of the magnetic pattern following a class 2 + flare appearance has also been reported by Deubner (1965). Schmidt (1964), who investigated the great flare of 16 July 1959, found large and rapid changes in the total magnetic flux, but less variations in the geometrical flux distribution. On the other hand, no significant changes in the sunspot field strength were found by Teske (1965) during a class 2 flare. The stability of solar magnetic fields in the regions of flares was briefly discussed by J. W. Warwick (1964).

From simultaneous magnetographic records of magnetic fields in the Hα and λ5250 lines and central intensities of these lines Severny (1966*a*, *b*) concluded that the class 1 + flare of 4 October 1965 appeared at the place of opposite directions of the photospheric and chromospheric magnetic fields. Moreton and Severny (1966, 1967) carried out a careful examination of the position of the first brightenings of flares on maps of longitudinal and transversal magnetic fields for the active group of 17–24 September 1963. Their analysis shows: (1) That the first brightenings occur simultaneously in widely separated regions being separated by neutral line of the magnetic field; (2) At least one of these bright knots lies immediately adjacent to the neutral line in the region of the greatest field gradient; (3) All flares tended to occur in two centres: the first one where the transverse field vectors were crossing and another one where strong oppositely directed currents appeared. In a similar study, Martres *et al.* (1966*b*) have shown that if a flare consists of two or more bright points, these are distributed along both sides of a line of change of magnetic polarities. Ioshpa and Obridko (1965*c*) found bright flare filaments extended along the neutral line and parallel to it. Azimuths of the transverse field were found perpendicular each to the other in the two flare filaments. Most of these results were also confirmed by S. F. Smith and Ramsey (1966). The association of a class 2 flare with the longitudinal magnetic field of the active region was also discussed by Banos (1967). McKenna (1965*b*) called attention to the fact that a part of the class 3 flare of 10 November 1960 originated above a region containing a strong transverse magnetic field.

The macroscopic and microscopic structures of flares and their relations to spots, magnetic fields and filaments, were reviewed by Kiepenheuer (1964*a*, 1965). Gopasyuk (1964) has found that the velocities of descending and ascending gases in sunspots increase during the flares. A model of the magnetic field in major flares, particularly applicable to proton flares of the A type, has been proposed by Banin (1966*b*).

The appearance of strong flares is often preceded by the appearance of new spots or by an intensification of spots, previously existing near the seats of flares (Shaposhnikova and Ogir 1966). Antalová (1965) found an interdependence between the proper motion of sunspots and the occurence of flares in their close vicinity as well as changes in the area of sunspots close to ribbon-shaped flares. In disagreement with this conclusion, no striking dependence between motions in complex sunspot groups and flare occurrence could be found by Kuklin and Syklen (1966). Howard (1963) studied flares associated with GLE. In each case the nearby spot group decreased in area from the day before to the day after the flare. The association of solar flares with sunspots has also been discussed by McIntosh (1965).

7.3. *Proton flares and forecasts*

Lists of proton flares were published by Malitson (1963), Švestka and Olmr (1966) and Dvoryashin (1966). General characteristics of proton flares were summarized by Dvoryashin (1964*a*, 1965), Malville (1964) and Pick (1966). Thirty-two proton flares before 1955 have been detected on the basis of vertical incidence ionospheric soundings (Švestka 1966*d*). Proton flares during the sunspot cycles 12 to 18 were identified by Bhargava and Subrahmanyan (1966) from an analysis of the amplitudes of geomagnetic sudden commencements.

Avignon *et al.* (1964*a*, *b*, 1965) have described typical configurations of proton flares. The configuration A, which is most efficient in producing PCA's, appears over spots belonging to a centre consisting of two sets of spots of opposite polarities separated by a small distance. Bruzek (1964*a*, *b*) has proved a close relationship between loop prominence systems and proton flares. Vinogradov (1964) could not find any difference in SID's produced by proton and non-proton flares. On the other hand, some associations between X-ray emission and proton flares were found by Dvoryashin (1964*b*, 1965).

Predictions of solar flares were discussed by Firor and Lilliequist (1965). In the U.S.A., ESSA and SFCRL are each engaged in forecasting solar disturbances on an experimental basis (U.S.A. Report 1966). On the basis of PCA observations during three solar cycles, the proton flare occurrence in 1966–68 has been predicted by Švestka (1966*b*, *d*). Weddell (1964) suggested a statistical method of the prediction of flares about one month in advance. Dodson and Hedeman (1964*a*) found an unexplained variation of solar proton events in a period of 29·5 days.

7.4. *Flare spectra*

Review papers on spectrographic observations of flares were presented by Zirin (1964*a*) and Severny (1965*e*). Švestka (1965*a*) reviewed the methods of the spectral analysis of flares and critically summarized the results obtained until 1964.

Systematic analysis of the Balmer spectrum of solar flares observed in projection against the solar disk were presented by Švestka (1965*a*) and by de Feiter (1966). Evidence of Stark broadening has been given and the electron density was computed by the halfwidth method for several flares. Švestka also proposed several methods for determining the optical thickness of flares and estimated the electron temperature. Deviations from thermal equilibrium (b_n factors) were determined for several flares (Švestka 1964*c*, 1965*a*) and a filamentary structure of flares appears to be the only possible explanation of the found results. Another evidence of the filamentary flare structure is the non-existence of Balmer continuum emission in disk flares. The observational evidence of the filamentary structure was summarized (Švestka 1965*b*) and a schematic flare model with filamentary structure was presented (Švestka 1965*a*). From the point of view of the filamentary structure, unavailable and available methods of the spectral analysis of flares have been distinguished. Ciurla and Rompolt (1965) computed the influence of the filamentary structure on the line profiles of prominences and flares.

The halfwidth method of determining n_e in flares was corrected for electron damping by de Feiter (1964, 1966). Time variation of n_e in a proton flare was determined (de Feiter and Švestka 1964) and n_e values for a number of flares deduced (Fritzová-Švestková and Švestka 1966*b*). They vary from 4×10^{13} cm^{-3} in the flash state of a class 3+ proton flare to 5×10^{12} cm^{-3} in limb flares. The state of excitation in a flare, as it can be derived from the observed Balmer decrement, has been compared by de Feiter (1966) with theoretical computations of the population of the energy levels of hydrogen for various physical conditions outside local thermodynamic equilibrium, taking 20 discrete levels and the continuum into account. As one of the results, the filamentary structure of flares is found again.

Hydrogen Balmer spectra of individual flares on the disk were studied by Kurochka (1964*a*), Guseynov (1965*b*) and Banin (1965*c*). While Banin's results ($n_e = 3 \times 10^{13}$ cm^{-3}) are in agreement with those mentioned above, Kurochka and Guseynov found Doppler broadening of Balmer lines. Highest velocities are found for hydrogen and lowest velocities for metals. Banin has also discussed profiles which appear if both Doppler and Stark broadening are present.

Many authors investigated hydrogen flare spectra on the limb. Kurochka (1965, 1966) found all lines broadened by Doppler effect with nonthermal velocities of several tens of kilometers per second and electron temperature lower than 10 000 °K. He gives $N_2(\mathrm{H}) \simeq 2 \times 10^{14}$ cm^{-2} and $N_1(\mathrm{Ca\ II}) \simeq 5 \times 10^{13}$ cm^{-2}. Doppler broadening was also found by Polupan (1964), who discussed several hundreds of photometric profiles for the flare of 27 July 1961. Polupan and Yakovkin (1965) solved stationarity equations for the first six levels of the hydrogen atom and compared these data with observations of this flare. As the result, they found $n_e = 2 \times 10^{12}$ cm^{-3} and $T_e = 7500$ °K for $h = 10''$ above the limb and confirmed the filamentary structure of flares. In a bright pulsating phenomenon on the limb, Gurtovenko and Kostik (1964) found $n_e = 2 \times 10^{11}$ cm^{-3} and $T_e = 11\,000$ °K. Shilova (1966) estimated the Lyman-alpha radiation flux in a limb flare as 30–100 times higher than in the quiet chromosphere. Differences between disk and limb flares were discussed by Švestka (1964*a*, 1965*a*). He also computed the influence of seeing on the line profiles, which might change in some cases the true Stark profiles in Doppler-like contours (1965*a*).

Helium lines in flare spectra were studied by Banin (1965*c*), Goldberg-Rogozinskaya (1965) and Kubeš (1965). In the helium regions of a disk flare, Banin found $T_e = 17\,000$ °K and nonthermal velocity equal to 5 km s^{-1}. The optical thickness of the D_3 line in spectra of 8 flares was found by Kubeš within the range of 1 to 5 and nonthermal velocity resulted to 5–20 km s^{-1} assuming $T_e = 15\,000$ °K. Quite different results were deduced by Goldberg-Rogozinskaya for a limb flare: $n_e = 10^{10}$ cm^{-3}, $T_e = 30\,000$ °K for He I and 50 000 °K for He II regions. Zirin's (1964*b*) study of three He II lines in the limb proton flare of 20 November 1960, showed that the spectrum of He II was due to pure recombination. From continuum radiation, Zirin deduced $n_e = 10^{11}$ cm^{-3}. Most of the material in the observed part of the flare was at coronal temperature. Bray (1964) found a different time-development of two flares in the hydrogen and helium (D_3) lines and suggested that this difference was due to differences in the mode of excitation of these lines. Banin and Prokofieva (1966) also observed that helium and metal emission in the flare of 26 September 1963, were delayed in comparison with the hydrogen lines.

A method of determination of the flare optical thickness in the H and K lines has been proposed by Kurochka (1964*b*). A method of constructing and solving the emission curve of growth for a flare on the disk was developed by Letfus (1964). An application of this method to the flare of 20 July 1958 led to the following results: $n_e = 6 \times 10^{13}$ cm^{-3}, $T_{exc} = 4690$ °K for Fe I and 5350 °K for Fe II, $T_{ion} = 6850$ °K, nonthermal velocity equal to 5·8 km s^{-1}. When analysing Ca II, Al I, and Mg I emission lines in flares, Alikaeva (1965) found $n_e = 1$ to 5×10^{13} cm^{-3} and $T_e = 9000$–$13\,000$ °K, varying during the flare development. Lower electron temperature and higher electron density were deduced from Na I lines (Alikaeva 1966). Geometrical thickness of calcium threads in a class 2 flare was found equal to 10^5–10^6 cm (Alikaeva 1964). According to Banin (1964) the emission of metals in coronal flare regions is similar to that observed in sunspot prominences and differs from that in chromospheric flare regions. Banin (1965*a*) has also found that metal lines with the upper excitation potential of $\sim 5{\cdot}5$ eV brighten most rapidly during the flare increase and those with $\sim 3{\cdot}3$ eV somewhat more slowly. The brightening of other lines is considerably slower.

The line asymmetry in flare spectra has been explained by Fritzová-Švestková (1964*c*) as due to an asymmetrical turbulent motion and by Ballario (1964, 1965) as due to the loop-type motions in the flare. According to Banin (1965*a, b*) the asymmetry is caused by a strengthening of the red wing of the line as a result of superposition of the additional emission of matter inflowing into the flare. Guseynov (1966*b*), too, explains the asymmetry as due to an additional emission. A flare model consisting of two loops has been proposed by Banin (1965*b*, 1966*a*).

A review paper on the continuous emission of flares in the visible spectral region was presented by Švestka (1966*a*). Korchak (1965) has shown that an interpretation of the visible flare continuum by synchrotron radiation of relativistic electrons meets with serious difficulties, if compared with the X-ray and radiowave spectral regions. Švestka (1966*c*) has called attention to the fact that the continuous emission of flares in the visual region could be explained by the H$^-$ emission if it appeared in low parts of flares, in which the Lyman-alpha radiation temperature is lower than 7500 °K and the density of hydrogen atoms exceeds 10^{15} cm^{-3}.

7·5. *Flare theories*

Flare theories were reviewed by Wentzel (1964*a*) and by Sweet (1965) and brief general comments on theories of flares were made by Parker (1964*a*) and by Goldberg (1966).

The manner in which the dissipation of magnetic energy can occur in the sudden events of flares was discussed by Gold (1964, 1965). Sweet (1964) pointed out the possibility of a large-scale resistive instability which could account for the sudden onset of flares. A plasma instability, which is able to produce dissipation of the magnetic field energy within an extended region and a sufficiently short time, has been suggested by Jaggi (1964, 1965). It appears if two dipole magnetic fields in the solar atmosphere approach each other and—as the result—a finite conductivity instability occurs. Dungey (1965) has discussed hyperbolic magnetic null points in a plasma, in which a thin sheet of intense currents can be formed. When the current density has grown, various kinds of instability may occur.

A very significant contribution to the Sweet's mechanism was presented by Petschek (1964) who took into account standing magneto-hydrodynamic waves as a possible mechanism for converting magnetic energy to plasma energy. The found rapid rate at which energy can be released removes the criticism that the release of magnetically stored energy is too slow. A simple two-dimensional model of Sweet's mechanism was discussed by Green (1965) to determine the rate of interpenetration of two anti-parallel magnetic fields. A dynamic dissipation mechanism of the magnetic field, leading to a direct transition of magnetic energy to that of fast particles, has been proposed by Syrovatsky (1966). The process of the ejection of condensations observed after flares was discussed by Livshitz and Pikelner (1964). The condensations are connected with the formation and separation of loops on lines of force of the sunspot field.

Sturrock and Coppi (1964, 1966) have proposed a new model of solar flares, in which the preflare state consists of a mass of gas supported by a sheared magnetic field. The flash phase of a solar flare is identified with a gravitational resistive instability of this plasma-field configuration. The instability tends to break up the plasma into filaments with dimensions of a kilometer or less. In another model, proposed by Wentzel (1964*b*), the flare is caused by the collapse of an unstable chromospheric region under the action of magnetic fields. The collapse is stopped by forces which are due to the compression of the magnetic field and as soon as the velocity of collapse becomes comparable to Alfvén speeds, turbulence is likely to occur. The optical emission is localized in thin surfaces at the eddy boundaries. Both these theories are able to explain the filamentary structure of flares as well as many flare-associated phenomena.

A theory supported by laboratory experiments has been proposed by Jacobsen and Carlqvist (1964) and by Alfvén and Carlqvist (1967): An energy comparable with the total energy of a solar flare, is stored in the magnetic fields connected with filamentary electric currents, which flow through the solar atmosphere. An interruption of the current-carrying plasma filaments leads to a rapid release of the stored magnetic energy at the point of interruption. Dubov (1966*b*) published some comments on the laboratory modelling of solar events. A theory of a powerful point explosion as the source of a flare was suggested by Guseynov (1964*a*, 1965*a*). The temperature in the centre of the explosion was estimated to $5 \times 10^6 - 8 \times 10^7$ °K depending of the flare importance. The brightening of flocculi in the surroundings of a flare (Guseynov 1964*b*) and turbulence in flares (Guseynov 1966*a*) were also discussed from the point of view of this theory. An explanation of flares by point explosions in a non-homogeneous atmosphere was also discussed by Obashev (1965*b*). Kiepenheuer (1964*a*, 1965), on the other hand, does not believe that the flare phenomenon is a macroscopic explosion or collapse. He suspects that subtelescopic distorsions and twisting of the associated magnetic field are the basic processes leading to a flare. Zwaan (1965*b*) finds the origin of flares in spasmodic changes in sunspots, by means of which matter is ejected into the chromosphere. Oster (1966) and Oster and Sofia (1966) suspect that an origin of the flare in the photosphere or even below the photosphere cannot be excluded. This conclusion is based on the results of computation of radiative cooling under conditions to be expected in flares. Also Blizard (1965) presented a hypothesis on the origin of flares in subphotospheric levels.

On the other hand, many authors have suspected than an acceleration of fast particles is the primary process in flares (Dubov 1963, Carmichael 1964, H. Elliot 1964, Sakurai 1965*a*, 1966*a*, and de Feiter 1966). Carmichael suggests that the primary energy involved in flares is the mechanical energy of the solar wind coming from the active region. When a collapse occurs, the energy of the magnetic field is first utilized in the acceleration of particles in the corona and the optical flare results from the descent of these high energy particles into the chromosphere. According to Sakurai, a collapse of the magnetic field occurs in either the upper chromosphere or the lower corona and the released energy is consumed in the acceleration of trapped particles. In association with a penetration of the stream of accelerated electrons into the lower chromosphere, the Hα flare originates. Accelerated electron streams also produce X-ray bursts by bremstrahlung, excite plasma oscillations in the corona and generate type III radio bursts. De Feiter suggests that the optical emission of flares is brought about by a downward propagating ionizing agent which originates in the high energy region whose existence is inferred from X-ray and radio bursts. The inhomogeneous structure of the Balmer flare is due to irregularities of this ionizing stream, which propagate along lines of force. According to Elliot the energetic protons are permanently present in the active region as trapped particles in the sunspot magnetic fields and the flare is the direct consequence of a catastrophic loss of these particles in the chromosphere. Kawabata (1966*a*) has suggested that ejection of a plasma cloud producing a geomagnetic storm is of primary importance with respect to the origin of the flare phenomena. A magnetically isolated cloud, which appears due to a reconnection of magnetic lines of force, is accelerated in consequence of inhomogeneities in the magnetic pressure and squeezed out from the sunspot region. The consequent collapse of the coronal condensation gives rise to the observed flare phenomenon. Assuming a sudden heating of the corona above flare, Wentzel and Solinger (1966) consider a shock moving downward from the heated region. Its effect may relate to the flare nimbus and to the disappearance of striation patterns.

From the high tritium and helium-3 content in Discoverer–17 material, Fireman (1964) concluded that nuclear reactions had occurred on the solar surface during the 12 November 1960 flare. The production of neutrons and gamma rays by nuclear reactions on the Sun was estimated by Chubb (1964). Wentzel (1965) has demonstrated that Fermi acceleration in a limited region near solar flares involves many attractive features so that it should remain under consideration.

7.6. *Optical flare—associated phenomena*

Observations of coronal and prominence phenomena associated with flares were reviewed by Zirin (1965*a*). A general discussion of transient flare-associated phenomena in the solar atmosphere was presented by G. F. Anderson (1966). Surges accompanying flares were studied by Zhang He-qi and Cao Tian-jun (1964), by Morgante and Torrisi (1965) and by Obashev (1965*a*). The Chinese authors pointed out the close relation of radio events to these ejections. Obashev estimated the kinetic energy of a limb surge. High-velocity surges associated with a limb flare were described by Valníček (1964*a*). An intrinsically close connection between surges and the small circular flares on their bases was emphasized by Bruzek (1966*a*), who found some similarity between the fine structure of the surge flare and the structure inside the associated surge.

When discussing the series of large flares which occurred in July 1961, Bruzek (1965) paid particular attention to associated loop prominences; the moving material accompanying the flare of 16 July 1959 was discussed by Dodson and Hedeman (1964*a*). For other studies of the association of loop prominences with flares see section 8. Slonim (1964, 1965) has concluded that in flares associated with loop prominence systems, the photospheric, chromospheric and coronal gases are mixed up in the flare region.

Observations of individual explosive-type flares and associated filament activations were described by Moreton (1964*b*) and by Morgante and Torrisi (1965). Moreton (1965*b*) also summarized the observed filament changes closely linked with the flare process. Other papers dealing with the filament activation by flares are mentioned in section 8.

Motions connected with moustaches were investigated by Koval (1964). In absorption lines moustaches are accompanied by shifts to the shortwave side and by jets to the longwave side, and the velocity increases with the height. The brightness asymmetry of the emission lines in spectra of moustaches is explained as due to a weakening of the moustache emission by absorption ejections (Koval 1965*a*). The position of moustaches in a spot group relative to the magnetic field was studied by Howard and Harvey (1964) and by Koval (1965*b*). According to Koval, moustaches appear mainly near the line dividing the magnetic field polarities $H_{||} = 0$ and at the border of the penumbra of large spots in the regions of interspersion of transversal fields.

Öhman (1966*d*) has found several cases where the Hα spectrum of a flare shows the two emission peaks of the low chromosphere at the limb suggesting central absorption due to mottles situated above the flare.

8. PROMINENCES

Prominence classifications have been extended through sunspot cycle No. 19 (Menzel and Jones 1963). Also of general interest is the production of a catalogue of eruptive prominences for the years 1938 to 1961 (Kleczek 1964*c*). Comparative studies in this catalogue have shown that the most active eruptive prominences occur during solar maxima. The indices employed for describing solar filament activity were analysed by Forti *et al.* (1965).

Extensive observational data on prominence line spectra have been given by Tandberg-Hanssen (1964*a*). The line lists given here seem comprehensive enough to form a catalogue of solar prominence lines. A list of equivalent widths of 194 lines in the spectrum of an active prominence observed at the solar eclipse on 15 February 1961, was given by Sotirovski (1965). Of particular interest is the observational material presented by Tandberg-Hanssen (1967) on the relative strengths of a number of He I prominence lines. It is established that the intensity ratio of corresponding singlet and triplet lines is strongly dependent on the activity of the prominence. Tandberg-Hanssen (1964*b*) also discussed the emission of Ba II lines observed in dense quiescent prominences, which pointed to conditions far removed from LTE.

Monochromatic studies of prominence forms have led to further observations of dark structures in the Hα and D_3 images (Valníček 1965*b*, Gahm 1966).

Spectra of quiescent prominences were studied by Melnikov *et al.* (1964) and by Zeldina and Sergeeva (1966). Morozhenko (1964, 1965, 1966) analysed hydrogen and metallic filaments in quiescent prominences, Zeldina (1964) applied the curve of growth, Piunov (1964*a*) proposed a method of determining Doppler halfwidths of Balmer lines taking selfabsorption into account, and Gurtovenko and Rakhubovsky (1965) discussed the Balmer decrement in prominences. Theoretical studies of a quiescent prominence spectrum obtained at the 1958 eclipse (Hirayama 1964) indicate that hydrogen ionization in prominences is due to Lyman continuum radiation which penetrates into the gas. According to Kawaguchi's (1964, 1965) discussion, this result implies a finely threated structure for a quiescent prominence. Yakovkin and Zeldina (1964*a*, *b*, 1965) have concluded that the prominence emission in the low Balmer lines are due to resonance scattering of photospheric radiation, while in higher lines, the emission is due to recombination. According to Stoyanova (1964), the observed relative populations correspond to excitation by photospheric radiation up to $n = 9$. The influence of systematic motions on the Hα profile was studied by Rompolt (1967). Kostik and Orlova (1964) studied profiles of Balmer lines in the spectrum of a dark filament and the same authors (1966) explained the bright hem of dark filaments in the Hα line as due to an additional excitation of the chromosphere caused by the photospheric radiation reflected from the filament.

Spectra of an active prominence were studied by Piunov (1964*b*, 1965), who found electron density $\sim 8 \times 10^{11}$ cm^{-3} and neutral hydrogen concentration $\sim 4 \times 10^{12}$ cm^{-3}. Teryaeva-Geichenko (1963, 1964) studied spectra of surges both on the disk and above the limb. The mechanism of excitation of the 3rd to 6th hydrogen levels is the photospheric radiation and radiative recombinations (Geichenko 1966). Yakovkin and Zeldina (1964*c*) have concluded that also the Hα radiation of eruptive prominences can be fully explained by scattered photospheric light. Švestka (1964*d*) pointed out the different behaviour of halfwidths of high Balmer lines in spectra of active prominences and flares. The effect on line equivalent widths of a filamentary prominence model was discussed by Rompolt and Ciurla (1967).

Recent progress in our knowledge of the condensation process of solar prominences has been surveyed by Kleczek (1965). Some general considerations on the energy balance as a factor in the evolution and structure of prominences have been set down by Menzel and Doherty (1963), Doherty and Menzel (1965) and Menzel (1965). Progress to an understanding of the generation and development of prominences from coronal material is, however, still held up pending a quantitative understanding of the mechanical heat input into the corona—especially its dependence on density and temperature. The question is considered further by Kuperus (1965) in a study of the initial phases of prominence formation and of the inbalance between mechanical heating by hydromagnetic waves and radiative cooling. The character and rate of heating of a solar prominence by the surrounding corona was considered by Ioshpa (1965). According to his considerations, not accounting for the radiative heat loss, a prominence without any internal magnetic field would be heated within less than one hour.

Observations of longitudinal magnetic fields in prominences have progressed in the past three years. Reports presented by Ioshpa (1963), Hyder (1964*a*), Lee *et al.* (1965), and Rust (1966) indicate that field strengths in quiescent prominences range from about 2 to 10 G, while active prominences and loops are associated with substantially stronger fields. In active prominences associated with flares, the magnetic field can reach to some hundred of gauss (Ioshpa *et al.* 1964). Ioshpa (1966) found a two-layer structure of the magnetic vector in the region of a quiescent filament. The supposition that the magnetic fields in prominences change their polarity in subsequent cycles, seems to have been confirmed by Hyder (1964*b*). The association of magnetic fields specifically with loop prominence configurations was discussed by Hyder (1964*a*) and by Kleczek (1964*a*). Kleczek (1963*b*) has shown that, since the motion of the prominence plasma is controlled by magnetic fields, rising loop systems imply a conveyance of field into the corona. There remains some question, however, as to whether the observed upward growth of loop systems is to be attributed to growth of individual loops or to the formation, at successively greater elevations, of new prominence loops. Rompolt (1965*a*) constructed a scheme of the magnetic field above an active region on the basis of recurrent trajectories followed by the active prominence matter.

A theoretical study of the emission line polarization produced by resonance scattering is given by J. W. Warwick and Hyder (1965). A comparison of the predictions with observational data shows that this cannot be accounted for without incorporating the influences on the degree and direction of polarization of magnetic fields and electron collisions. Hyder's (1965*b*) polariscope observations of quiescent prominences give promise of useful data if extended over a solar cycle. Active prominences show a larger polarization degree than the quiescent ones (Brückner 1965). Observations of strong polarization in the continuous spectrum of a flare spray are reported by Öhman *et al.* (1967). The (linear) polarization is consistent with an origin in Thomson scattering by free electrons.

Studies of the association of loop prominence formation with large proton flares and type IV radio bursts indicate that loops are a manifestation of the storage in the corona of fast, non-thermal, particles (Jefferies and Orrall 1964, Bruzek 1964*a*, *b*). This view gains credibility from observations of extremely broad, non-gaussian Hα wings in loop systems (Jefferies and Orrall 1965*a*, Orrall 1965*b*). Further support is found from comparison of the mass in a coronal condensation and that which is drained down the loops during the lifetime of the system (Kleczek 1964*a*, Jefferies and Orrall 1965*b*). A possible mode of expansion of loop prominences was discussed by Fokker (1964).

Filament activation by active regions has also been extensively studied. Vertical Doppler shifts giving rise to the appearance of 'winking' filaments have been discussed by Dodson and Hedeman (1964*a*), S. F. Smith and Ramsey (1964), Prokopieva (1964) and Ramsey and S. F. Smith (1965, 1966). Observations in the red and blue wings of Hα show that the material seems to exhibit up and down motion of an oscillatory nature. Each filament appears to have its own characteristic frequency of oscillation, repeating this frequency with each subsequent disturbance. Some typical changes in the filaments appear already several minutes or tens of minutes before the flare appearance: Hyder's (1966) theoretical study has aimed at interpreting this oscillatory phenomenon as a damped harmonic oscillation of conducting material resting in a magnetic field whose strength varies with height. It is suggested that winking filaments and 'disparitions brusques' may be different manifestations of a common phenomenon, the one being a stable, the other an unstable oscillation. The nature of the driving force generated by a flare and initiating the oscillation has been considered by G. F. Anderson (1966) and by Meyer (1966). Valníček (1964*b*) compared the velocity changes of matter emanating from explosive-type flares and blow-off prominences and found a difference in the nature of these two processes. A different type of activation leading to filament breakup by developing sunspots is reported by Bumba and Howard (1965*a*).

Yet another connection between filaments and active regions is found by S. F. Smith (1965) in the observations of 'sympathetic' flares formed along (or under) filaments which themselves had been flare activated within the preceding 30 minutes or so. As pointed out by Tandberg-Hanssen (1967), this observation, if confirmed, can have highly important implications to the flare mechanism.

Prominence activity stimulated by or associated with adjacent surge and flare activity has also been discussed by Liszka (1963, 1964). The circumstances surrounding the occurrence of a giant eruptive prominence, and the subsequent history of the gas are set down by Hedeman and Dodson (1966).

An interesting study of the suppression (by about 0·3 km s^{-1}) of the chromospheric oscillatory velocity field near a quiescent prominence has been made by Kleczek (1964*b*). The lifetime by quiescent prominences was studied by Forti and Godoli (1965) and found equal to 1·5 rotations, on the average.

Sturrock and Woodbury (1965) suggest that quiescent filaments result from slippage of the photosphere, which occurs preferentially along a neutral line, and a model filament has been calculated by them. McLean (1964) has considered equilibrium configurations of the magnetic field which may apply to quiescent arch prominences. Chvojková (1965*b*, 1966*a*) and Chvojková and Klepešta (1965) have shown that some phenomena observed in eruptive prominences can be explained if the effect of gravity is taken into account when considering plasma particles frozen in the magnetic field.

9. CORONAL CONDENSATIONS AND ACTIVITY

In 1963, two Symposia were held, which contained many papers concerning the problem of this section: *The Solar Corona* (Evans 1963) and *The Solar Spectrum* (de Jager 1965*a*). A review paper on the interpretation of coronal observations in X-ray, UV, visible and radio wavelengths was presented by Seaton (1964) and contemporary ideas on physical properties of the solar corona in connection with chromospheric activity and radio bursts were reviewed by J. W. Warwick (1965*b*).

In the solar corona, the distinguishing between active and 'quiet' conditions is particularly difficult. Therefore, at least four basic papers which perhaps do not seem to be directly connected with the active corona, have to be mentioned here, because, in fact, they are very important for studies of the active coronal regions as well: Burgess and Seaton (1964) and Burgess (1964) pointed out the role of dielectronic recombination in the process of formation of the emission coronal lines. And Pottasch (1963, 1964) presented very important papers on the element abundances in the corona.

Perturbing agents in the chromosphere and corona causing magnetic storms with and without ssc were studied by Garczynska (1965). The same author also investigated the velocities of shock waves in solar corona at the time of flares (Garczynska 1967). Parker (1964*c*) discussed the response of the coronal medium to shock waves produced by flares.

Many papers have been published which deduce physical properties of the solar corona from radiowave and X-ray observations. These are mentioned in sections 10 and 11.

Papers discussing monochromatic solar corona are more frequent than those concerning the K-corona, which is obviously due to difficulties arising from observations of the K-corona outside the eclipse. Nevertheless, many papers on the monochromatic corona are also based on eclipse observations. Suzuki and Hirayama (1964) and Letfus (1965) have presented models of coronal condensations, which are in accordance with the temperature computations based on the abovementioned Burgess' dielectronic recombination and Pottasch's abundances. Suzuki and Hirayama have assumed an inhomogeneous temperature distribution in the studied coronal condensation observed at the eclipse of 15 February, 1952, and find the abundances of iron and nickel 10 times higher than in the photosphere. Letfus has discussed the Fe XIV $\lambda 5303$ and Fe X $\lambda 6374$ emission line intensities in two condensations observed in 1952 and 1962; for a cylindrical model he finds central temperature 4 to 5×10^6 °K from the green line and about half of this value from the red line. These temperature differences are explained by a filamentary structure of the coronal condensation. Spectra of coronal condensations containing loop prominences were studied by Orrall (1965*c*). Electron temperature 2×10^6 °K and electron density 2×10^9 cm^{-3} were found in the condensation, the density being 50 times lower than that for the loop prominence in the Hα emitting region. Assuming rough pressure equilibrium between the prominence and the rest of the condensation, a model for the loop structure of a sporadic condensation has been proposed. The possibility that matter in the coronal condensation is largely concentrated in the loop system has also been considered by Tsubaki (1966). Saito and Billings (1964) presented a model of the condensation based on polarimetric observations of the condensation on the western limb during the February 5, 1962 eclipse.

Coronagraphic observations have been used, particularly, in studies of associations between various forms of the solar activity. Kleczek (1963*a*) investigated relations between green ($\lambda 5303$) loops and arches with the underlying photospheric magnetic fields. The same problem was also discussed by Bumba *et al.* (1965). The authors have found that the brightest coronal features tend to be associated with the highest gradients in the photospheric magnetic fields. Křivský and Makarov (1966) have studied the deformation of the green corona after nine selected proton flares which appeared close to the limb and conclude that the condensations are deformed in non-radial directions. Nagasawa and Nakagomi (1965) studied the intensity of the green coronal line in connection with the birth and decay of a calcium plage. They have shown that the coronal activity has a tendency to appear before the birth and to disappear only after the death of a calcium plage. An attempt has been made by Shpitalnaya (1964) to analyse events preceding the formation of bright knots in the green coronal line. She observed a stream collision at the boundary separating the coronal condensation from the undisturbed corona resulting in 'dashes' developed in the He D_3 line at the heights from 30″ to 60″ above the limb. Zirin's (1964*b*) observations of the limb proton flare of 20 November 1960, have led to the conclusion that a substantial fraction of the coronal condensation may be at temperatures exceeding 4×10^6 °K. Vsechsvyatsky *et al.* (1966) used pictures of the corona taken during the eclipse on 30 May 1965, to study correlations between the corona and the chromospheric and photospheric activity. Kernoa *et al.* (1965) compared intensities of 12 coronal lines photographed at the eclipse of 15 February 1961, in 'hot' and 'cold' points of the corona. Schmieder *et al.* (1967) have shown that the intensity ratio of Ni XV λλ6702 and 8024 lines is more sensitive to the electron density in coronal condensations than the ratio of Fe XIII lines discussed earlier by Perche and Dumont (1964).

Some papers based on coronagraphic observations and studying correlations of coronal characteristics with the 11-year cycle are mentioned in section 3. Apart from them, Gentili *et al.* (1966) compared variations of the λλ5303 and 6374 coronal line intensities during the 18th and 19th solar cycles, on the basis of Pic-du-Midi observations. Significant differences could only be found in the λ6374 line behaviour near the solar minimum.

Almost all studies of the K-corona have been based on eclipse observations. At the eclipse of 1961, Kawaguchi (1967) studied a coronal dome formation overarching a prominence. The condensation photographed by Saito during the eclipse of 1962, was discussed by Saito and Billings (1964). At the eclipse of 1963, Stoddard *et al.* (1966) observed polar rays and J. W. Harvey (1965) made an attempt to associate them with the polar magnetic field of the Sun on the basis of K_3 spectroheliograms. And several papers are based on observations of the eclipse of 1965: Leroy and Servajean (1966) investigated the brightness of the K-corona in the immediate neighbourhood (3000 km) of a prominence. No appreciable brightness variation larger than 5% could be found. Saito (1964) photographed the polar rays and having compared these photographs with the earlier ones he deduced an 11-year variation of the length of the hypothetic dipole whose lines of force might be identical with these rays. Finally, Bohlin *et al.* (1966) used solar eclipse photographs of 30 May 1965, photographs from the balloon-borne coronagraph flights (Coronascope II, Newkirk and Bohlin 1965) of 3 June and 1 July 1965 and nearly synoptic K-coronameter scans from 1 May to 31 July 1965 and achieved in this way a unique combination of coronal data covering several solar rotations. This has allowed basic phenomenological features of one major streamer to be established in the region $1 < \rho < 5$. The streamer lifetime was at least two months, its rotation was in agreement with that of surface features at the streamer latitude and the streamer exhibited a spiraling of the classical Achrimedian form due to the rotation of the Sun. Surveyor I made the first observation of the solar corona from the lunar surface on 14 June 1966 (Newkirk 1967).

Regular observations of the K-corona are not yet frequent enough to make any study on the cyclic variations possible. Nevertheless, Nishi and Nagasawa (1964) have succeeded to find a correlation between coronal streamers and the quiescent prominences. Nakagomi and Nishi (1965) have made a statistical study comparing the solar electron corona and the green coronal line intensity with various photospheric and chromospheric phenomena. They conclude that regions of the maximum polarized component of the K-corona appear over active regions where they correspond to coronal condensations as well as outside active regions where they indicate the coronal streamers.

Kuperus (1965) made an attempt to explain the origin of permanent coronal condensations in terms of the excess heating of these parts of the atmosphere, due to an enhancement of the mechanical energy flux. He has shown that fluctuations of the mechanical energy flux give rise to coronal inhomogeneities. Bird's (1965) theoretical considerations lead to the conclusion that the maximum coronal temperature does not vary significantly with the initial heat imput within very broad limits. If however, the heat imput exceeds some critical limit, as may be the case with solar flares, the maximum coronal temperature begins to increase rapidly. The energy balance in a coronal condensation, considered as a magnetic tube of force, has been investigated by Obashev (1964). His study of the loss of energy of the electronic component of coronal condensations shows that the cooling caused by radiation and thermal conductivity takes a very short time (about 10 minutes).

10. RADIO ASPECTS OF SOLAR ACTIVITY

10.1. *Reviews and general papers*

General review papers on solar radio emission were written by Maxwell (1965) and Smerd (1964*a*). Relationships between solar radio emission and X-emission were reviewed by Kundu (1963, 1964), and theoretical aspects of particle and radio emission were discussed in a critical review paper by Schatzman (1965*b*). General papers on flare-associated radio phenomena are those of Ellison and Reid (1964), Wild (1964), de Jager (1965*c*), and McLean (1965). A review paper on the observation and physical interpretation of solar radio bursts was presented by Wild *et al.* (1963) and by Smerd (1964*b*).

The origin of type I and II bursts and of reverse-drift pairs connected with type III emission was discussed by Zheleznyakov (1965*b*). Frequencies of electromagnetic waves originating when fast-moving particles pass through a magnetized plasma were computed by Ginzburg (1964). The possibility of amplifying radio waves in a plasma was discussed by Smerd (1965). Gelfreikh (1964) studied the depolarization and transfer of radiation in plasma in the presence of an arbitrary magnetic field. The magneto-ionic theory in relation to solar radio emission was critically discussed by Wallis (1965*a*). Fung and Yip (1966) have shown that in the solar corona, electrons moving in the magnetic field of a sunspot may generate cyclotron radiation, which will be observable mainly in the ordinary mode in the vicinity of the second harmonic of the cyclotron frequency.

Kawabata (1966*a*) tried to explain the flare-associated bursts from the point of view of his new flare theory (cf. section 7.5). Takakura (1964) made an attempt to derive information on the magnetic field intensity in the corona from known characteristics of type I, II, III, and IV bursts and on the basis of various assumptions as to the mechanisms involved. The same author (Takakura 1966) discussed the general implications of solar radio bursts for the study of the corona.

10.2. *The slowly varying component*

Review papers on slowly varying component at microwaves were written by Swarup (1964), Pick (1965) and Hachenberg (1965).

Caroubalos (1964*a*, 1965), Das Gupta and Basu (1964), Krüger *et al.* (1964) and H. Tanaka (1964) dealt with the variation of the slowly varying component through the solar cycle. Two maxima of the solar radio emission flux during the 19th cycle were found by Gnevyshev (1965), in agreement with other manifestations of the solar activity (cf. section 3). Attention has been drawn to the fact that the degree of correlation between the 10·7 cm flux and the EUV solar radiation varies with solar cycle (A. D. Anderson 1964, 1965). A phase-shift of the 27-day variation for 10·7 cm and 21 cm flux was discussed by Sastry (1966).

Combining the results of observations made at Toyokawa and at Nançay, H. Tanaka and Steinberg (1964) derived the structure of the polarized microwave source above a bipolar sunspot. Khangildin (1964) studied the Sun's radio brightness distribution at 8 mm and obtained evidence for the existence of small sources right above sunspots with brightness temperatures of 7 to 10 × 10^4 °K. A reduced radio brightness was found to be connected with certain filaments. The same author (Khangildin 1965) also measured the polarization of 8 mm radiation from selected active regions. On the basis of observations carried out with a 17 GHz grating interferometer, Tsuchiya and Nagane (1967) found the sources of the slowly varying component optically thin at this frequency. The spectral distribution of the slowly varying component was discussed by Molchanov (1964*a*), Krüger and Michel (1965), and Abbasov *et al.* (1965). Krüger and Michel found evidence for the existence of a secondary maximum near 1500 MHz, apart from the well-known maximum near 6000 MHz.

Solar eclipses were used to measurements of discrete sources by Higgs and Broten (1964)

Gosachinsky *et al.* (1964) and Hett (1966). The Soviet authors detected an aborption region, which could be identified with a limb prominence. High-resolution observations of a partial solar eclipse at 9·1 cm were described by Asper *et al.* (1964). Characteristic properties of solar radio sources associated with plages without sunspots were discussed by Abbasov and Yasnov (1966).

M. Simon (1965) found regions of enhanced 3·2 mm emission to correspond with Hα active regions, particularly so with those that are prone to flare production. Active regions that later flared were considerably enhanced for a day or more prior to the flare. Avignon *et al.* (1966) established a relationship between certain properties of the slowly varying component and the optical structure of the associated centre of activity. On the contrary, Soboleva (1965) did not find any dependence of the centimeter and dekameter radio emission on the type of the sunspot group. H. Tanaka and Kakinuma (1964) noted a relation between the spectrum of the slowly varying component and the occurrence of proton flare events. Most of the proton flares occurred in active regions which had the 3·2 to 7·5 cm flux ratio greater than unity. On the other hand, Eliseyev and Moiseyev (1965) found that regions with and without proton flares do not differ with regard to the intensity of the slowly varying component of radio emission at 9 and 21 cm. The centres of 21 cm condensations are shifted to the east relative to the spot with the largest magnetic field. Ikhsanova (1964) who carried out simultaneous measurements at 3·15 and 8·7 cm, found a shift of coronal condensations towards the equator with regard to the sunspots. An increase of the radio emission associated with rapid revival of a sunspot group was studied by Borovik *et al.* (1965).

Magneto-bremsstrahlung has been considered as the mechanism producing the $2 \text{ cm} < \lambda < 20 \text{ cm}$ slowly varying component by Molchanov (1964*b*) and by Grebinsky and Molchanov (1964).

10.3. *Noise storms*

A review paper on noise storms was presented by Fokker (1965). Work on noise storms done with the 169 MHz interferometer at Nançay was summarized by Le Squeren (1964*a*). Elgaröy (1965) summarized narrow-band studies of solar bursts made at Oslo. De Groot (1966) gave an extensive account of the narrow-band spectra and other properties of weak stormbursts as observed with a 7-channel receiver. In addition to many examples of observed bursts he presented a discussion on possibilities of interpretation. Some properties of the storm-centres at 408 MHz were deduced by Clavelier (1967). Noise storms at 200 MHz were studied by Yurovskaya (1964). A new classification of solar radio storms in the meter range has been proposed by Tlamicha *et al.* (1964).

Wild and Tlamicha (1964, 1965) called attention to the occurrence of chains of stormbursts which often show a drift in frequency. This phenomenon was also discussed by Hanasz (1966). Eckhoff (1966) introduced the name 'flash burst' for bursts with a duration of the order of 0·1 second which occur isolated during ordinary noise storms or, very rarely in groups. These flash bursts seem to be identical to the 'spike bursts' which were noted previously by de Groot (1962, 1966).

Trachtengertz (1966) criticized the Takakura's (1963) theory of type I solar radio bursts and suggested that interaction of accelerated coronal electrons with magnetohydrodynamic impulses could be considered for a possible mechanism of the generation of type I radio bursts. Mogilevsky (1966*a*) has presented a hypothesis that narrow-band type I bursts are due to forbidden transitions between split Zeeman sub-levels of the ground state in hydrogen atoms.

10.4. *Bursts of type II, III, and V*

J. W. Warwick (1965*a*) summarized the results of sweep-frequency observations in the range of 7·6 to 41 MHz, made at the High Altitude Observatory, Boulder. Observational material of type II bursts was studied by the late A. A. Weiss (1965) to derive the velocity of the sources as a function of height. He discussed the results in terms of a magneto-hydrodynamic shock front. The question how radio emission can be generated in shock fronts was discussed by Zaitsev (1965) and Tidman (1965). Both theories account for the existence of a first and a second harmonic. Zaitsev, in addition, ascribes band splitting to electron drift in the shock front. Takakura (1964), A. A. Weiss (1965), Formichev and Chertok (1965) and Krishnamurthi *et al.* (1965) made estimates of the strength of the magnetic field on the basis of characteristics of type II bursts and various hypotheses about their mechanism. Takakura estimates a field strength of about 15 G at a height of $1{\cdot}5 \times 10^5$ km; for the same height Fomichev and Chertok derive a value of 5 to 8 G. According to these authors the field strength at a height of 4×10^5 should be 1·2 to 2 G, while Krishnamurthi *et al.* found 3 to 8 G. The estimate of Weiss lies between 2 and 20 G for a height of $3{\cdot}5 \times 10^5$ km. Stewart (1966) found that the fast drifting spectral features known as 'herring bones' that diverge from a type II bursts, sometimes exhibit strong circular polarization, in contrast to the type II bursts themselves. Drago and Tagliaferri (1966) found that the association percentage between subflares and type II bursts was increasing towards the minimum of solar activity, which is interpreted as a consequence of coronal electron density variation with the solar cycle.

Observations of type III bursts were extended to as low a frequency as 1·5 MHz by means of sweep-frequency recordings on board of the Alouette satellite (Hartz 1964). Frequency drift curves indicate velocities in the range of 0·1 *c* to 0·15 *c*. De Groot (1966) dealt with high-speed records of weak type III bursts. With the help of observations made with the panoramic spectrograph at Boulder, some characteristics of type III bursts were studied by Boischot (1966). Solar type III bursts were also observed with a swept frequency receiver in the 200 MHz range by Elgaröy and Rödberg (1964). Evidence of an increase in the source size on the way out through the corona was presented.

The polarization of type III bursts was studied by several authors. Bhonsle and McNarry (1964*a*) determined polarization ellipses at 74 MHz. Daene and Voigt (1964) reported on both linear and circular polarization of type III bursts at 23 MHz. Gopala Rao (1965), from sweep-frequency observations from 40 to 60 MHz, noted a double structure of the type III burst with differently polarized components. The sporadic circular polarization of type III bursts at 200 MHz was studied by Enome (1964).

Velocities in the range *c*/6 to *c*/2 were derived by Stewart (1965) for the outward motion of sources of type III bursts. He concluded that this should be the actual velocity of the electron cloud. Malitson and Erickson (1966) determined positions of type III bursts at 26·3 MHz with a multi-element interferometer. From these observations, the coronal electron density above the active region was found 10 times higher than in the Van de Hulst model of the equatorial maximum corona. Likewise Morimoto (1964) found a density 3 times as great as the density in a streamer, according to the Newkirk model.

Tlamicha and Takakura (1963, 1964) found a good coincidence in position between active prominences and filaments and groups of type III bursts at 200 MHz. In the sunspot group of September 1963, Zirin and Werner (1967) found for almost every type III burst a corresponding Hα brightening in the active region, but not all brightenings produced bursts. In another active region McKenna (1966) could discover a specific brightening within ± 1 minute of the start of 96% of all the radio events studied. Records of intense type III bursts on the night hemisphere of the Earth were reported by Fortini *et al.* (1966).

The properties of type V bursts were studied by A. A. Weiss and Stewart (1965). Heights and sizes are similar to those of type III bursts. The authors suggest that type V emission stems from coherent Čerenkov plasma waves excited by fast (*c*/3) electrons that oscillate between magnetic mirror points.

A. A. Weiss and Wild (1964) computed trajectories of charged particles in the vicinity of magnetic neutral planes. They were able to account for observed features of type III bursts assuming an exponential decrease of magnetic field strength with height. Sturrock (1964) discussed several properties of type III bursts on the supposition that type III emission is related, by coupling, to plasma oscillations excited by electron streams. A similar study was made by Oster and Altschuler (1964).

In March 1966, many narrow-band width bursts, apparently of a type not so far reported, were observed by Ellis and McCulloch (1966) in the frequency range 20–50 MHz.

10.5. *Type IV bursts*

A compilation of flux density, polarization and positions for type IV bursts was published by Kai (1965*a*). A list of 174 type IV events recorded from 1956 to 1963 was prepared by Švestka and Olmr (1966). A collection of spectral diagrams, based on single frequency records, was published by Fokker (1966). Some aspects of type IV continuum radiation on decimeter wavelengths were discussed by Kundu (1965*b*).

Sakurai (1964, 1965*b*) found an east-west asymmetry in the differences in onset time of the microwave and metric continuum components, which he explains by the assumption of a westward-inclined magnetic field structure. Malitson and Erickson (1965, 1966) reported on a moving type IV burst on 11 August 1963 and on the location of solar continuum emission at 26·3 MHz during the period from 18 to 25 September 1963. A fast moving type IV event was also reported by Philip (1964) according to measurements at frequencies from 13 to 23 MHz made with a multichannel interferometer. During a class 3 flare time variations in the radio emission were found by McKenna (1965*a*) closely associated with fluctuations of the Hα intensity of an optical flare region over the umbra of a major spot. In the course of the type IV burst of 5 February 1965 observed by Aller *et al.* (1966) at 230 MHz, four short-lived absorption events were recorded, each with the duration of about 1 second.

In two papers, Kai (1965*b*, *c*) first gave a thorough account of observed polarization characteristics of type IV bursts. He then deals with the possibilities of interpreting the polarizations: (*a*) on the basis of gyroresonance radiation; (*b*) on the basis of radiation from coherent plasma waves. In an appendix the emissivities and absorption coefficients for gyrating electrons are derived on the basis of expressions worked out by Kawabata (1964). Other contributions to the theory of type IV bursts were given by Böhme (1964*a*) and McLean (1964). On account of the influence which the ambient plasma exerts on synchrotron emission, Zheleznyakov and Trakhtengertz (1965) specified a condition which is imposed on the generation of synchrotron radiation.

Křivský (1964, 1965*a*) made a supposition that the delayed type IV burst on 16 September 1963 was produced by the cloud of ejected particles during its passage through the interplanetary space. This supposition was modified by J. Elliott and I. H. Reid (1966).

For the correlation of type IV bursts with proton flares cf. section 7.3. The radio evidence for solar corpuscular emission was summarized by Maxwell *et al.* (1964). The occurrence of type IV bursts in the course of the 11-year solar cycle was studied by Křivský and Krüger (1966); two maxima of occurrence have been found.

Radio spectra of selected type IV bursts were described by Tsimakhovich (1964), Suzuki *et al.* (1964), Yurovskaya (1965), Hagen and Barney (1966), and Castelli and Michael (1967). Machalski and Zieba (1965) investigated the correlation between 810 MHz radio bursts and solar flares.

10.6. *Microwave bursts*

The continuous spectrum of solar microwave bursts was studied by Hachenberg and Krüger (1964). They found flux densities increasing monotonically towards higher frequencies, generated by thermal radiation, as well as broad emission bands with maxima at various frequencies, produced by synchrotron radiation and in most cases a combination of both these two mechanisms occurred. Similar results were obtained by Dravskikh (1964). Takakura and Kai (1966) presented inferences on the energy distribution of electrons that produce impulsive microwave bursts and X-ray bursts. From the study of the microwave emission of flares, which appeared beyond the limb, Erushev (1966) has concluded that upper borders of sources of microwave bursts are localized at the height of some tens of thousands kilometers above the photosphere.

McKenna (1964) commented on the 'late' 10 cm maximum in particle producing flares. According to Eliseyev and Moiseyev (1965), in active regions with proton flares the number of flares accompanied by microwave bursts exceeds that in regions without proton flares by a factor of 3 to 4. G. A. Harvey (1965) has concluded that proton flares are accompanied by very characteristic broad profile bursts at 2800 MHz, which might enable an easy recognizing of proton events. This observation is in good agreement with the Fletcher's (1964) conclusion that the most important frequency interval for the correlation of type IV bursts with proton flares is 1000–3750 MHz. Haurwitz (1964) found that particularly flares which activated dark filaments were highly productive of 2800 MHz radio bursts.

Erushev and Eliseyeva (1965) compared the microwave bursts at 3·2 cm with SID's and direct X-ray records. A similar comparison was made by G. A. Harvey (1964) for microwave bursts at 10·7 cm. Bursts unaccompanied by SWF seem to originate in lower layers than the SWF producing bursts. The different centre-limb variation in the numbers of flares producing SID's and microwave bursts, has been tentatively explained by Mergentaler (1965).

Berger and Malville (1966) have proved that the hydrogen 3 cm emission line cannot be observed in the flare radio spectrum.

II. SOLAR EUV RADIATION, X- AND GAMMA-RAYS

General review papers on this subject were presented by Friedman (1963), Tousey (1964), de Jager (1964*a*), Winckler (1964), and Mandelshtam (1965*a*). A very detailed review paper was prepared by Mandelshtam (1965*b*) and a critical one by de Jager (1965*f*) who also suggested a classification for flare-associated X-ray bursts. Relationship between solar radio and X-emission were reviewed by Kundu (1963) and de Jager (1965*d*). Allen (1965) summarized variations of the XUV solar spectrum due to solar activity. The review paper written by Tousey *et al.* (1965) deals with EUV spectroheliograms and with results of the research carried out with rocket-borne grating spectrographs. Results summarized by Lindsay (1964) are particularly based on the OSO–1 measurements. Naval Research Laboratory results were summarized by Friedman (1964*a*) and results achieved in the United Kingdom were reviewed by Pounds (1965).

Direct spectroheliograms at a variety of wavelengths show close correlation with plage activity. Monochromatic pictures of the Sun in Mg II λ2803 line were obtained during two rocket flights, using a Šolc birefringent filter with ∼ 4 Å passband (Fredga 1966). The older regions were found more intense than the younger ones, which is opposite to the effect observed in the Hα line. A solar photograph obtained from a rocket flight in the spectral region within 170 to 400 Å was discussed by Zhitnik *et al.* (1964). Blake *et al.* (1964, 1965) found that X-ray sources observed at ∼ 50 Å were spread over areas of the order of 6′ in diameter and larger, comparable to the underlying plages, whereas strong ∼ 10 Å sources were always smaller than 2′. These results imply that a coronal condensation is a complex structure containing small, hot centres embedded in a large lower temperature region. Essentially all the radiation at ∼ 10 Å originated in active regions only, while about one half of ∼ 50 Å emission was distributed over the disk. An estimate for the size of the X-ray emitting region was also given by Reidy (1966).

Four flights of Skylark rockets carrying equipments for X-ray solar photographs, were launched from August to October 1965. Results achieved with the first flight (passband 44–70 Å and < 25 Å) were described by Russell (1965*a*) and by Black *et al.* (1965). The second flight has shown that bright X-ray plages are observed even one day before the appearance or one day after disappearance of optical plages (Russell 1965*b*). During the third flight the Sun was photographed in He II λ304 and Fe IX λ171 lines (Burton and Wilson 1965). With the fourth flight, the < 50 Å source dimensions were found smaller than 1′ for three active regions (Russell and Pounds 1966). For the first time, dark regions were clearly visible on the disk, probably marking regions of lower coronal density. Photographs of the Sun within 3 to 75 Å region obtained with glancing incidence telescopes aboard an Aerobee rocket, were described by Underwood and Muney (1967). Earlier results deduced from X-ray photographs of the Sun were summarized by Mandelshtam (1965*c*).

Observations of EUV line emission carried out aboard OSO–1 were discussed by Neupert (1964, 1965, 1967). It has been estimated that the Fe XV and Fe XVI emission in plages is approximately 150 to 200 times that of an equivalent area of the quiet Sun, while for the He II λ304 line this ratio is about 15. The intensity ratio Fe XVI/Fe XV depends on the phase of development of active regions and increases during flares. The observations are inconsistent with an increase of electron temperature, but they are consistent with a model for active regions, which postulates both an increase of electron density together with an *increase in the vertical range over which the Fe XV and Fe XVI radiation is emitted.* Electron temperature of $1{\cdot}75 \times 10^6$ °K best fits the observed data. This can be compared with Widing's (1966) estimate of $T_e = 3$ to 5×10^6 °K in an active region emitting Fe XV and Fe XVI. Blake *et al.* (1965) have also concluded that the X-ray emission of plages is dominated by X-ray line radiation from iron of ionization states XV and above. Fe XVII was found to come from the active plage only. This has also been confirmed by flux variations in different lines with solar activity (Neupert *et al.* 1964, Hinteregger *et al.* 1964, Hall *et al.* 1965*a*, *b*, Austin *et al.* 1966). The flux ratio of Fe XV λ284 and He II λ304 lines decreased from 0·25 to $\sim$0·04 during the period August 1960–March 1964. Between 170 and 300 Å, a continuum emission has been recorded from intense centres of activity (Tousey *et al.* 1965). Strong lines in the 170–180 Å region were discussed by Elston *et al.* (1964) and the range 72–105 Å was photographed on the first time in February 1966 (Austin *et al.* 1966).

Suemoto and Moriyama (1964) have pointed out that EUV line intensities are too strong if compared with the radio intensities. This discrepancy disappears if one assumes that the solar disk is bright only in patches covering about 0·15 of its total area. Stockhausen (1965) has shown that an existence of inhomogeneities in the corona with densities of $\sim 10^{10}$ cm^{-3} can be inferred from the observed correlation of the Fe XIV line strengths with solar activity.

Variations of the solar X-ray spectrum below 20 Å under non-flare and flare-active conditions were studied by Culhane *et al.* (1964). Chubb *et al.* (1964) compared the spectral energy of solar X-rays from 2 to 20 keV under quiet conditions and during subflare activity. In the second case, an emission peak was found near 10 to 12 keV, which might be evidence of an intensification of emission associated with Fe XXV and Fe XXVI ions. Typical non-flare and flare-enhanced X-ray spectra were obtained with the satellite Ariel in the range 4 to 14 Å (Bowen *et al.* 1964). The non-flare spectra are supposed to arise from discrete hot regions in the corona, with $T_e = 5 \times 10^6$ °K. In flares, as far as their emission is of thermal origin, T_e corresponds to $\sim 1{\cdot}2 \times 10^7$ °K. In case the X-ray emitting region has the extent of the visible flare, $n_e = 4 \times 10^{10}$ cm^{-3} is found. Tindo and Shurygin (1965) measured X-ray radiation between 2 and 18 Å during two rocket flights and compared the results with the distribution and brightness temperature of active regions present on the disk.

An analysis of X-ray data (< 10 Å) from the OSO–1 satellite has shown that the slowly varying component of X-rays and the non-impulsive X-ray bursts can be well related to their microwave counterparts (W. A. White 1964). Correlation of X-ray flares with 2800 MHz events is better than with Hα observation. Lindsay (1965) has also concluded that bursts of X-ray radiation associated with flares coincide extremely well with 3750 MHz data even as far as common secondary maxima are concerned. On the other hand, the correlation between X-ray and Hα flares is much worse (Van Allen *et al.* 1965, Conner *et al.* 1965), and particularly bad as to the flare importances. There are many Hα flares without any X-ray bursts. X-ray measurements made aboard Electron–2 have been described by Tindo (1965) and they confirm many of the conclusions mentioned above. Very good correlation is found with 10·7 cm radio flux again.

X-ray measurements carried out with the SOLRAD satellites were discussed by Kreplin and Gregory (1965) and by Thomas *et al.* (1965). According to the X-ray flux the solar minimum occurred in July 1964. Friedman (1964*b*) gives that during the solar cycle the X-ray emission varies by the factor 7 for $\lambda < 100$ Å, 70 for $\lambda < 12$ Å, and 300 for $\lambda < 8$ Å. Landini *et al.* (1966*a*, *b*) used the 1965–93 A satellite for an observation of the partial solar eclipse in X-rays. Sudden and deep changes of X-ray intensity were observed when the Moon's limb covered or uncovered active regions. No changes of this type were observed in the UV (1225–1350 Å) region.

Five X-ray flare bursts observed aboard OSO–1 were discussed by Frost (1964, 1965). He has found, in agreement with Kundu's (1963) analysis that an impulsive microwave burst was associated with every X-ray burst, which was not the case for type III bursts and other meter wave events. This fact has also been confirmed by Chubb *et al.* (1966) who have concluded from it that the X-ray emission region is located in the chromosphere rather than in the corona. Korchak (1965*b*) also places the X-ray source in the upper chromosphere. On the contrary, Kawabata (1966*b*) shows that the X-ray source must be located in the coronal region, since an X-ray event on 4 September 1960, was associated with a flare behind the solar limb. A similar conclusion has been drawn by Tindo (1965) from the fact that X-regions appear earlier on the eastern limb and disappear later on the west than optical active regions. Zirin (1964*b*) estimates that the X-ray emission comes from 30 000 km in the corona. Moreton (1964*a*, 1965*a*) drew attention to the fact that all high-energy (> 20 keV) X-ray events were connected to flares of the explosive type. The extraordinary enhancements of X-ray emission associated with the flares of 6 and 7 August 1960, were explained by Švestka (1964*b*), on the basis of flare spectra, as due to an increased density in the active region in which the flares appeared.

Chubb *et al.* (1966) presented an improved analysis of X-ray measurements in the $h\nu > 20$ keV region, carried out from rockets during three class 2+ flares in 1959. Two of these flares showed spectra equivalent to that expected from a thermal plasma with $T_e \simeq 10^8$ °K. Other events can be explained by thermal radiation, too, if the balloon measurements are properly corrected. The authors stress that there currently exists no definitive observational evidence for non-thermal X-ray emission.

SID effects were used to a study of solar X-ray bursts by several authors: Fortini (1963) has found similar trend of SEA and SCNA events if produced by flares recurring in the same area of an active region and she ascribes it to the influence of persistent magnetic fields that control the particle motion; a thermal model does not seem capable of explaining these recurrent characteristics. On the basis of ionospheric measurements, Odincova (1964) has made an estimate of the intensity distribution below 1000 Å in the spectrum of the flare of 28 August 1958. SEA data were analysed by Erushev (1965) who estimated that the maximum energy X-ray flux below 2 Å varied within 10^{-7} to 10^{-3} erg cm^{-2} s^{-1} in various flares. Neshpor (1965) deduced a time variation of the X-ray spectrum during the flare of 23 November 1957, from SID records. Eliseyeva (1966) has confirmed that X-ray flares do not correspond to type III bursts.

On the basis of an analysis of simultaneous observations of X-ray emission of the Fe XV and Fe XVI lines and 10·7 cm radio emission, Shklovsky (1964) has shown that a coronal temperature of $\sim 1{\cdot}5 \times 10^6$ °K is sufficient to explain the X-ray emission on the quiet Sun. The X-ray emission of flares is explained by the inverse Compton effect on relativistic electrons with energies $\sim 10^7$ to 10^8 eV. Zheleznyakov (1965*a*), too, presented the same explanation. On the other hand, Acton (1965*a*) concludes that the X-ray emission of flares cannot be explained by the inverse Compton effect and shows that the solar flare radiation can be explained by thermal processes if $T_e = 4 - 5 \times 10^6$ °K (Acton 1965*b*). Acton (1965*c*) also suggested that X-rays in flares might be produced by electron transitions among inner K–, L–, and M– spheres, in consequence of an ionization by energetic electrons. Korchak (1965*b*) concludes that the X-ray emission is due to bremsstrahlung of non-relativistic and sub-relativistic electrons. The X-ray burst accompanying the flare of 28 September 1961, could be explained by Korchak (1965*a*) by bremsstrahlung if the particle density in the breaking levels was two orders higher than in the undisturbed atmosphere. If the electron energy spectrum is extrapolated to relativistic energies, the observed centimeter burst can be explained as well. Elwert (1964), too, tried to combine X-ray, radio and particle observations of a flare in one homogeneous system. According to the later Korchak's (1965*b*) paper, however, it seems unlikely that a single mechanism will provide a smooth fit from X-rays to radio bursts.

Possible mechanisms of γ-ray production in solar flares were discussed by Dolan (1964) and by Dolan and Fazio (1965). Until now, however, all trials to detect γ-rays from the Sun, have given negative results (Fazio 1964, Kraushaar *et al.* 1965, Frye and Reines 1966).

12. HIGH ENERGY PARTICLES

A detailed general summary on solar proton events was presented in the NASA Solar Proton Manual edited by McDonald (1963). Review papers on high-density particles emitted from the Sun were published by Obayashi (1964*a*, *b*), K. A. Anderson (1964*b*), Roederer (1964*a*, *b*), de Jager (1965*e*) and Ogilvie (1965). A very illustrative critical review paper on particle and radio emission from the Sun was presented by Schatzman (1965*b*). Malitson and Webber (1963) and Webber (1964) described general characteristics of solar cosmic ray events and Fichtel *et al.* (1963) summarized details of individual solar particle events. Lists of PCA events were given by Bailey (1964), Basler and Owren (1964), Cummings (1965), Fritzová-Švestková and Švestka (1966*a*) and, for the period before 1956, by Švestka (1966*d*). Solar proton events during the IQSY period were summarized by Goedecke *et al.* (1967).

Křivský (1965*c*, 1966) studied the flight time of solar protons to the Earth and discussed a space model of the clouds of high-energy protons ejected from flares (1965*b*). Van Allen *et al.* (1964), Hakura (1965), Leinbach *et al.* (1965), Chivers and Burrows (1966), and Adams and Masley (1966) investigated relations of PCA records to the energy spectrum of high-energy particles and the progressive softening of the spectrum during the PCA development. Yoshida and Akasofu (1965) have shown that solar flares associated with cosmic-ray increases are the most energetic throughout the entire range of the energy spectrum of solar particles. Shea and Smart (1965) proposed an analytical method to analyse flare-associated cosmic ray increases, effectively including as many stations as possible.

Statistical comparison of flares and flare-associated phenomena with ground-base measurements of cosmic rays were made by Vladimirsky and Pankratov (1964), Dorman *et al.* (1964), Yoshida (1965) and Vladimirsky *et al.* (1966). In the last two papers, a definite statistical increase of solar cosmic rays ($\sim 0{\cdot}5\%$) has been found for meter type IV bursts and X-ray flares. Cosmic-ray increases not associated with solar flares have been suspected by Dorman *et al.* (1965). Chirkov *et al.* (1965) and Kuzmin *et al.* (1965) studied cosmic-ray variations associated with active regions passing over the solar disk in December 1957 and in July 1961, respectively. Vladimirsky (1965*a*) expressed an idea that all solar flares produce low-energy cosmic rays.

The number of papers dealing with observations of high-energy particles from space vehicles has increased many-fold since the last report. In this section we discuss mostly the flare-associated events; for other observations see section 13.

K. A. Anderson (1964*a*) re-examined the solar proton flare events of late August 1957. Arnoldy *et al.* (1964) made a comparison of the cosmic radiation measurements from the Earth, balloon ion chambers and Pioneer–5 during the March–April 1960 events. Four solar proton events observed by Explorers XII and XIV were discussed by Bryant *et al.* (1964, 1965*a*). They have found that the rate of propagation of protons is linearly related to particle velocity, such that the time to reach maximum intensity is inversely proportional to velocity and conclude that the propagation involves a degree of scattering that is independent of the energy. Charakhchan A. N. and T. V. (1965*a*) have shown that the differential energy spectrum of solar flare particles has the same exponent (~ 3) in the several hundred MeV range for various flares. In the higher energy range the spectrum exhibits a discontinuity and the exponent increases to 5–6. The location of the discontinuity is different in different flares. Softening also occurs after the onset of a magnetic storm (Vakulov *et al.* 1964, Charakhchan A. N. and T. V. 1965*b*). Spectra of high-energy solar protons were also studied by Ogilvie and Bryant (1964), Bennett (1964), Dorman and Miroshnichenko (1965, 1966), Laxutin (1965), Paulikas *et al.* (1966) and Charakhchan *et al.* (1966). The last authors found an indication that the diffusion coefficient of solar protons in the interplanetary space increased at about three-times from 1960 to 1963. Increases of lower-energy (~ 1 MeV) protons were recorded with several space probes and analysed by Krimigis and Van Allen (1966) and by Vernov *et al.* (1966*a*, *b*). Only some of these increases can be directly associated with solar flares.

The anisotropy of solar cosmic rays was studied by McCracken (1963) and by Kuzmin *et al.* (1965), but the most important anisotropy studies were made with the Pioneer 6 space probe, particularly at the proton event of 30 December 1965 (Fan *et al.* 1966, Bartley *et al.* 1966, McCracken and Ness 1966). It has been found that the cosmic ray anisotropy is well aligned with the interplanetary magnetic field and the direction of anisotropy is shown to exhibit marked and abrupt changes, well correlated with the changes in the direction of the magnetic field. The data from Pioneer 6 indicate the existence of large numbers of filamentary tubes, originating at the Sun but intertwined in interplanetary space. Cosmic rays are envisioned as constrained to the flux tubes.

The important role of α-particles in producing PCA's was shown by Weir and Brown (1964), and by Hakura (1965). The high-altitude balloon measurements of the relativistic solar α-particles in the late phase of the 12–13 November 1960 event were discussed by Yates (1964), who found a power law instead of the exponential rigidity spectrum. This result was criticized by Waddington and Freier (1965). The increased participation of α-particles after the onset of a sc geomagnetic storm was discussed by Sakurai (1965*d*).

Review papers on the composition of solar cosmic rays were presented by Fichtel (1964) and by Biswas and Fichtel (1965). Reviews of the results obtained from the study of cosmic rays with Soviet satellites and space probes, with a particular emphasis to the detection of nuclei heavier than protons were given by Ginzburg *et al.* (1963, 1964). The participation of heavy nuclei in solar cosmic rays was also discussed by Vladimirsky (1964). Cosmic-ray nuclei with $Z > 2$ have been observed after major flares on at least four occasions (Biswas *et al.* 1963, 1966, Biswas and Fichtel 1964). During the 18 July 1961 event the increase in the flux of medium nuclei ($6 \leqslant Z \leqslant 9$) was a factor 40 over the normal cosmic ray flux. Biswas and Fichtel (1964, 1965) concluded that the composition of the nuclei appeared to reflect the photospheric abundances. Quite an opposite conclusion, however, was made by Charakhchan A. N. and T. N. (1965). Increases of the flux of nuclei with $Z \geqslant 5$ and $Z \geqslant 15$ were also recorded aboard the Electron–2 satellite (Bloch *et al.* 1965, Kurnosova *et al.* 1966) and with the second Soviet cosmic rocket (Vladimirsky 1965*b*). Most of these increases, however, do not seem to be connected with solar flares and Vladimirsky suspects that one might meet there with a new effect associated with some solar events different from the flare phenomenon.

Solar neutrons may have been detected by means of balloon observations after an importance 3 flare. *A flux of* 148 ± 60 *neutrons* $m^{-2} s^{-1}$ *in the 20–160* MeV *range was determined* (Krishna Apparao *et al.* 1966). On the other hand, Vela satellites operating since October 1963 have not detected any neutron bursts in excess of $1 \cdot 5 \times 10^3$ neutrons/cm^2 integrated intensity even after importance 3 flares accompanied by type IV radio bursts (Blame and Asbridge 1966). Lingenfelter *et al.* (1965) calculated the intensity and energy spectrum of neutrons above 1 MeV produced by flare-accelerated protons and α-particles in the photosphere. They have found that bursts of solar neutrons following major flares should be observable at high altitudes. Roelof (1966) has shown that due to diffusion, neutron-decay protons are insensitive indicators of the presence of neutrons in solar flares and it is unlikely that neutrons from a flare can be detected by means of proton observations.

Evidence for solar-flare electrons was obtained from the IMP satellites (Cline *et al.* 1964, Cline 1966, K. A. Anderson and Lin 1966), Electron–2 satellite (Tindo 1965) and Mariner 4 space probe (Van Allen and Krimigis 1965). While the solar origin of the electron flux reported by Cline *et al.* is doubtful, the other authors found direct relations of the recorded bursts of electrons to bursts of radio noise and X-rays associated with flares. The western longitudes of all the flares suggest a restriction of the electrons to field lines with a half angle of 15–20°.

The acceleration of protons by hydromagnetic shocks induced in the corona by heating *due to flares was analysed by Weddell (1965). Solution of the relativistic equations of motion* of protons subject to the moving magnetic field accompanying a shock leads to results, which agree in several aspects with the observed characteristics of solar proton events, nevertheless the resulting proton flux seems to be much too small. Wentzel (1965) and Sakurai (1965*d*) consider the Fermi acceleration mechanism as the predominating process in accelerating solar cosmic rays from flares. Korff (1964) has concluded that the acceleration must take place at levels of about 100 000 km above the photosphere. The initial phase of a solar proton event was investigated by G. C. Reid (1964) and an attempt was made to treat the diffusion through the solar atmosphere in a quantitative fashion. The possibility of a storage of energetic particles in the corona was discussed by Malville (1964). Willis (1966) examined the motion of an isolated energetic charged particle in a force-free magnetic field with rectilinear lines of force. He has found that under certain conditions a particle travels predominantly across the magnetic lines of force and it is suggested that some energetic charged particles may be able to escape from force-free magnetic fields by this process. The propagation and diffusion of solar flare protons and the modulation of the energy spectrum in the interplanetary space were discussed by Parker (1964*d*), Ivanov and Kolomeets (1965), Fibich and Abraham (1965) and Shishov (1966). Krimigis (1965) suggested a unified interplanetary diffusion model and used it for an interpretation of the time history of the intensity of several cosmic ray events. Wibberenz (1966) pointed out the significance of drift motions for solar energetic particle propagation in interplanetary space.

13. SOLAR WIND DISTURBANCES

Review papers on solar corpuscular radiation including enhanced solar corpuscular emission were written by Krimigis (1963), Parker (1964*b*), Mustel (1964*a*, *b*, *c*) and by Colburn and Sonett (1966). Scientific findings of Mariner 2 were reviewed by Sonett (1963), and by Snyder and Neugebauer (1964, 1965). Some papers concerning solar wind disturbances also appeared in 'The Solar Wind' symposium edited by Mockin and Neugebauer (1966). Parker (1966) summarized his earlier ideas in a synthetic picture: Disturbed conditions in the interplanetary space result when there is more turbulence in the wind than usual and/or when there is a sudden increase of coronal temperature in association with a solar flare. The 27-day recurring disturbances are associated with narrow regions of turbulence between broad regions of wind. Sudden heating of the corona at the time of a solar flare results in a sudden increase in the rate of expansion of the corona giving a blast wave which propagates outward through the wind. Nevertheless, some authors still prefer the magnetic bottle model in its original Golds form, which has some advantage in explaining the flare-associated corpuscular emission in an illustrative way. Some common features of the Parker's and Gold's models were discussed by Santarelli (1965).

Using measurements aboard Mariner 2, Vela 2, IMP 1 and Explorer 14, new determinations of solar wind velocity and temperature were made by Wolfe and Silva (1965), Wolfe *et al.* (1966), Neugebauer and Snyder (1966) and Strong *et al.* (1966). From quiet to disturbed conditions, proton's velocity increases from slightly more than 300 km s^{-1} up to 800 km s^{-1}, temperature from the order of 10^4 °K up to 9×10^5 °K and proton density from ~ 5 to 80/cm^3. The maximum density usually appears at the leading (western) edge of each stream. The magnetic field temporarily increases well above 10 gamma in association with disturbances from the Sun (Ness *et al.* 1966*a*).

The interplanetary magnetic field is directly tied to and co-rotates with the solar photospheric magnetic fields. This has been shown dramatically from a comparison of IMP–1 magnetic field data with solar magnetograph observations. The magnetic lines of force extend in Archimedes spirals in accordance with Parker's theory of the solar wind. During the three-month interval of IMP–1 observations (1963 November 27 to 1964 February 17) the interplanetary field divided into 4 sectors, alternating in direction toward and away from the Sun. These sectors had correspondence to grossly averaged magnetic features in the photosphere (Ness and Wilcox 1964, Wilcox and Ness 1965, Ness 1966*b*, Ness and Wilcox 1966*a*, Smolkov 1966*b*, Sakurai 1966*b*, Ness *et al.* 1966*b*). Co-rotation of the systems of corpuscular streams also appears from the stability of the 27-day recurrence of geomagnetic disturbances (Vsechsvyatsky 1964, Lapointe 1964), cosmic ray intensity (Mori *et al.* 1964, Balasubrahmanyan *et al.* 1965), and proton increases (Gregory and Newdick 1964, Bryant *et al.* 1965*b*), and it has also been supported by measurements of Pioneer 6 and IMP–3 (Ness 1966*a*). Davis (1964, 1965, 1966), Davis *et al.* (1964, 1966), Coleman *et al.* (1966), Lazarus *et al.* (1966) and E. J. Smith *et al.* (1966) discussed observations made aboard Mariner 2 and 4, IMP–1 and OGO–1. It appears that the polarity pattern of the interplanetary field changed considerably between August 1962, where two reversals occurred per solar rotation, and November 1963, when the number of reversals was doubled. In late 1964, the Mariner 4 magnetometer recorded a 4-sector polarity pattern similar to that observed with IMP–1. Starting early in 1965, however, the Mariner-4 data show a considerable evolution of the patterns, which become less definite than they were earlier. This suggests that the pattern becomes less stable as the Sun becomes more active. However, at least one feature of the patterns may have persisted for the whole period of more than two years. Some observations of recurrent proton increases suggest a trapping of protons over certain regions (Bryant *et al.* 1963, 1965, McDonald and Desai 1966). Interplanetary magnetic fields co-rotating with the Sun apparently confine the protons from flares and 27-day recurring regions to given sectors and thus influence the appearance or non-appearance of protons at the Earth (O'Gallagher and Simpson 1966). Helium of solar origin in these recurrent particle streams was detected by Gloeckler (1965).

Snyder *et al.* (1963) have concluded that M–regions are the emitters of high-velocity plasma and Snyder (1964) tried to associate the solar wind velocity variations observed by Mariner 2 with observed plages on the Sun. Mustel (1965*b*) examined the two theories of the formation of quasistationary corpuscular streams from the Sun: (1) the streams originate in active regions, and (2) particles generated in undisturbed regions are deflected by neighbouring active regions. According to Mustel, all geomagnetic, satellite and space probe data confirm the first hypothesis. Nevertheless, many other authors consider the second alternative, i.e. the hypothesis of 'cone of avoidance' as the more favourable one, particularly Allen (1964), Saito (1964), Sinno (1964) and Nojima *et al.* (1964). The outflow of particles from M-regions was discussed by Piddington (1964) and Mustel (1966) and the structure that would be expected to develop when a fast stream in the solar wind is embedded in a slower ambient wind was considered by Hirshberg (1965). McCracken *et al.* (1967) report the observation, made with Pioneer 6, of a number of recurrent phenomena having all the characteristics of Forbush decreases apart from any flare-association. They were, however, ultimately correlated with recurrent M–regions.

The north-south asymmetry in the solar wind as observed with IMP–1 and 3 was discussed by Ness and Wilcox (1966*b*). Křivský and Letfus (1965) suppose that this asymmetry is due to an inclined interplanetary magnetic field caused by the galactic wind. The existence of a solar proton belt in a distance of 1·5–2 A.U. has been suggested by Vernov *et al.* (1966*c*) on the basis of proton flux measurements carried out aboard Zond 3 and Venus 2 space probes.

By comparing PCA events and Forbush-type decreases, Gosling (1964) proved a storage of high-energy protons in the cloud ejected from a flare and Haurwitz *et al.* (1966) and Švestka (1966*e*, 1967) deduced an asymmetrical magnetic field distribution in the cloud, with a magnetically strong western boundary. Geometrical dimensions and kinematic characteristics of solar corpuscular streams have been estimated by Mustel and Maisuradze (1966). A possibility of connection of two magnetic bottles in the interplanetary space was pointed out by Gopasyuk and Křivský (1967). From the interaction point plasma moves towards the Sun, as has actually been observed in some cases by Vitkevitch and Vlasov (1966) from the radio sources scintillation. A 'cleaning' of the interplanetary space by solar particle emissions was discussed by Lebeau *et al.* (1964) for the case of flares of 3 July 1957. The influence of the interplanetary magnetic fields on the propagation of solar protons was examined by Sakurai (1965*c*). Production of pairs of shock waves by the flare-associated enhanced solar wind was suggested by Sonett and Colburn (1965) and discussed by Sturrock and Spreiter (1965) and by M. Simon and Axford (1966). A scheme of permanent generation in active regions of corpuscular streams consisting of discrete plasmoids with own quasi force-free magnetic field has been offered by Mogilevsky (1964, 1965, 1966, Kalinin and Mogilevsky 1965). His analysis of the observations of magnetic fields in the interplanetary space confirms that the corpuscular streams with own magnetic field have a discrete structure.

Akasofu (1964) has tried to show that the solar plasma ejected from an active region can contain an appreciable amount of neutral hydrogen atoms. This supposition has been criticized both from the solar and geophysical points of view by Brandt and Hunten (1966) and by Cloutier (1966). Cloutier shows that the flux of neutral hydrogen is less than 10^{-5} of the total solar wind flux at 1 A.U.

14. SOLAR-TERRESTRIAL RELATIONS

Quite a lot of papers relating to the problems of solar-terrestrial physics, have already been mentioned in the preceding sections. Particularly, reader's attention is called to sections 7.3, 12, and 13.

Jonah *et al.* (1965) have prepared a five-volume catalogue which brings together the major optical, radio frequency, ionospheric and geomagnetic phenomena and events for the 19th solar cycle. Pick (1966) summarized the main optical and radioelectric properties of flares associated with SID, PCA and ssc magnetic storms. A synthetic study of severe solar-terrestrial disturbances of 9–12 February 1958, was presented by Hakura and Nagai (1964) and the same events were also described by Rivera and Gonzáles (1964).

Connections between the fine structure of type IV bursts and the production of PCA'S with long and short delay times were investigated by Böhme (1966). Bell (1963) has pointed out that type IV bursts which cover the full frequency range from microwaves to meter wavelength are strikingly more successful in the production of PCA events (as well as geomagnetic storms) than are type IV bursts limited to two or three octaves of the spectrum. Fritzová-Švestková and Švestka (1966*a*) investigated in detail the association between type IV burst flares and PCA events. They have concluded that strong PCA's are caused predominantly by flares between 10° E and 90° W on the solar disk and give the probability of PCA production by type IV burst flares as a function of the flare position on the disk. There seems, however, to be a general tendency of some active regions to emit or not to emit high-energy protons from type IV burst flares to the Earth.

Statistical association of flares with Forbush decreases during two solar cycles was studied by Krymsky and Shafer (1965). The series of Forbush effects of September 1963 was studied by Fischer and Křivský (1965). A close correlation between the integral flux of high-energy solar protons and the amplitude of the associated Forbush-type decrease has been found by Pankratov (1965).

Associations between flares, type IV bursts, and geomagnetic disturbances were studied by Akinjan and Dolginova (1965). Böhme (1964*b*) has found that intense type IV bursts produce, on the average, more intense geomagnetic storms and the corresponding delay time is shorter. Sudden commencement magnetic storms recorded at Zô-se during 1936 to 1962 were studied in association with solar flares and type IV bursts by Fan Chen (1965). Fritzová-Švestková and Hřebík (1964) have confirmed that there exist very important flares without any magnetic storm and major storms without any flare. They have also confirmed, however, that all flares associated with type IV bursts are sources of corpuscular streams. Fritzová-Švestková (1965) also studied the delay times of major and weak storms. Caroubalos (1964) established a statistical relationship between the delay time of geomagnetic storms and the radio energy emitted by the associated type IV burst.

Mustel and Egorova (1964, 1965) and Mustel (1965*a*) have shown that the recurrent geomagnetic disturbances are connected with the passage of active regions through the central solar meridian. Geoactive chromospheric flares are uniformly distributed over the solar disk, but the energy of the geomagnetic disturbance decreases with the increasing distance of the flare from the central meridian. According to Bell (1963), 80% of the major storms arise from flares located within 20° of the central meridian. Fritzová-Švestková (1966) deduced from the longitude distribution of flares producing major geomagnetic storms some conclusions on the density distribution and the trail curvature of the corpuscular streams ejected from flares. Billings and Roberts (1964) discussed the origin and some properties of the 27-day variations of geomagnetic activity from the point of view of Parker's model of the solar wind. The close correlation of central-meridian passages of unipolar magnetic regions with recurrent geomagnetic storms during the last solar minimum was discussed by Bumba and Howard (1966*b*). Ballario (1966) has examined the solar and geomagnetic activity during the IQSY Retrospective World Intervals for 1964 and 1965. She concludes that the observed K_p maxima are correlated with central meridian passages of regions in which plages, mostly associated with spot groups, show remarkable development changes.

Šťastná (1964) and Bateman and Oster (1965) verified the earlier Becker's result: If two sunspot groups are located at the same longitude but on the opposite hemispheres, their passage through the central meridian causes a decrease of the K_p index within approximately two days. If, however, the longitude difference increases to about 10°, the A_p index strongly increases. Šťastná suggests that this is connected in some way with the fact that in the first case opposite polarities, while in the second case identical polarities are located at the same longitude. Halenka (1967) makes an attempt to explain yearly variations of geomagnetic activity by an existence of two opposite active intervals of heliographic latitudes on the Sun.

Bednářová-Nováková (1964) and Halenka (1964) have tried to show that flares are not sources but only indicators of some events of the ejections of corpuscular streams from the Sun. They believe that the actual source of the corpuscular emission are filaments and the most geoactive phenomena on the Sun are filaments associated with unstable sunspot groups (Bednářová-Nováková 1964*a*, 1966*a*, Bednářová-Nováková *et al.* 1964, Halenka 1966*b*). Halenka (1966*a*) even tries to prove that geomagnetic storms erroneously ascribed to proton flares were caused, in fact, by central meridian passage of unstable filaments and Bednářová-Nováková (1967) opposes the opinion that sudden disappearance of filaments is caused by flares. Bednářová-Nováková (1966*b*) and Bednářová-Nováková *et al.* (1964) have also pointed out that when forecasting geomagnetic activity it is necessary to know the coronal formation extending over the solar central meridian at the given moment. This is in agreement with the conclusion made by Gnevyshev and Ol (1965) that the mean annual values of geomagnetic disturbances are connected with the intensity of the λ 5303 Å coronal line more closely than with any other index of solar activity.

15. ADMINISTRATIVE REPORT

Two working groups of Commission 10 were active during the reported period:

(*a*) The working group on CSSAR was established at the Hamburg meeting in 1964, in the following composition:

Michard (chairman), Dodson-Prince, Fokker, Giovanelli, Jefferies, Kiepenheuer, Righini, Roberts, Rösch, Severny, H. J. Smith, Švestka, Waldmeier.

(*b*) The working group on coronal intensity standardization was established in 1966 sponsored both by the IAU Commissions 10 and 12, in the following composition:

Rösch (chairman), Gnevyshev (secretary), Nagasawa, Newkirk, Waldmeier.

In fact, this is a re-establishment of an earlier Working Committee, which treated some problems of coronal observations in the period 1958–61. Many observers of the solar corona have been of the opinion that some more work on the standardization of coronal data is urgently needed. This working group has planned to hold a meeting at Bagnères-de-Bigorre before the Prague General Assembly, in August 1967.

Since important parts of the activity of these working groups are envisaged for 1967, i.e. after submitting the present Report for press, we have preferred not to include any partial reports here, and the chairmen of both these working groups will present verbal reports at the meetings of the Commission 10 in Prague.

The following recommendations are to be considered:

(1) A. H. Shapley recommends to discuss, from the point of view of Commission 10, the proposal to establish a solar-terrestrial service and its proposed status. This proposal is based on a resolution taken at the URSI XV Assembly, Munich 1966, calling on IUCSTP to make the study and potentially arrange for the establishment of such a service. Commission 10 could recommend for or against the establishment of such a service and make comments on its needs and terms of reference.

(2) A. H. Shapley recommends to discuss the experience with the new IAU classification of flare importances and to have a discussion whether other international standards may be needed as regards description of other forms of solar activity in addition to Hα flares. The possible need for such additional work on standardization of descriptions could benefit from a general discussion at Prague and eventually lead to establishment of an appropriate working group if there appears a need for it.

(3) A. H. Shapley would also be interested in having a discussion on the success of the IQSY solar activity forecasts and also whether the post-IQSY forecasts made and distributed

by IUWDS and potentially modified to serve non-solar-minimum conditions are useful or expressed in terms appropriate to the present understanding of the development of solar activity.

(4) A. D. Fokker recommends to devote a discussion to the *Quarterly Bulletin on Solar Activity*, with a particular emphasize on Resolution 3 of the last Hamburg meeting. This resolution concerns the possibility of contributing solar magnetograms to the Quarterly Bulletin.

(5) W. O. Roberts recommends that the *Quarterly Bulletin on Solar Activity* resume publication of solar data for the central region, discontinued in December 1938, and that the central region data for the period 1938 to the present be compiled and published.

(6) A. D. Fokker recommends to publish spectral diagrams of type IV bursts on a regular basis.

(7) A. D. Fokker has pointed out some highly desirable research activities to be carried out in the study of solar radio events: (*a*) Observations should aim at a more precise determination of the spectral profile of individual type I bursts. (*b*) Two-dimensional position determinations of individual stormbursts and determinations of their angular sizes will be most rewarding. (*c*) It is desirable that more detailed information on source sizes be obtained for all types of solar radio events and at several frequencies. (*d*) It is desirable to extend determinations of polarization ellipses for type III bursts to such an extent that, for one and the same burst, polarimetric observations be available at more than two different frequencies. (*d*) A knowledge of the actual form of the intensity curve of impulsive microwave bursts in its rising part may well be important for an understanding of the explosive phase of the flare phenomenon. (*f*) There is still a great want of more data on source positions and polarizations of type IV emission.

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