43. COMMISSION DE LA MAGNETO-HYDRODYNAMIQUE ET DE LA PHYSIQUE DES GAZ IONISES

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INTRODUCTION

This report deals only with those aspects of magnetohydrodynamics and plasma physics that are specifically of interest to astronomy. The emphasis is on theory; however, a number of observational papers are mentioned, both as background and because of interesting suggestions which they contain. Purely mathematical or physical theory is normally included only when its astronomical relevance is clear.

The topics discussed include solar and stellar magnetism, interplanetary and galactic fields, and the origin and propagation of cosmic rays. Problems referring to the magnetosphere are in general excluded as falling within geophysics; however, the tail of the magnetosphere and the sheath between the magnetospheric boundary and its associated bow shock are included, being the seat of processes which may have parallels in interstellar space. In spite of the significance of cosmic rays in X-ray sources, radiation is in general considered only in so far as it assists the diagnosis of charged-particle properties.

During the period covered by the report (1964–66), the proceedings of a number of conferences of interest to Commission 43 have been published. The most important of these were the 1964 conference on the Solar Wind (**1**) and the 1965 conference on Cosmic Rays (**2**).

THE SUN

Field structure

Much recent observational work has been concerned with the microstructure of solar fields. Severny (**3**) has written two detailed reports on the subject; Bumba (**4**) has given a general discussion of the relation between field and velocity structures. Severny (**5**) found that, whereas at low resolution the polar field may appear coherent, at high resolution it consists of elements differing in size, field strength and polarity. Stenflo (**6**) confirmed this result, finding that the mean field measured increases with decreasing slit area. Severny (**7**) has also studied the fine structure in height, and the corresponding shear of the field.

Leighton (**8**) developed Babcock's theory of the solar cycle, assuming the dispersal of magnetic regions to be the combined effect of non-uniform rotation and a random-walk process due to supergranulation currents. Sheeley (**9**) interpreted results for bipolar spots along these lines, pointing out that the fact that the numbers of polar faculae lag 90° in phase behind the sunspot numbers is consistent with the polar fields being fields of following spots carried to the poles in a few years by a random walk (see also Bumba and Howard (**10**)). Similarly Hyder (**11**) suggested that the 'rush to the poles' by prominence filaments synchronizes with the reversal of polar fields; Godoli and Mazzuconi (**12**) found that polar surges have maximum frequency at solar minimum, when the polar field attains its maximum.

The connection between supergranulation and field strengths has been stressed in a number of papers. Bumba and Howard (**13**) found that active regions and spots tend to develop in the spaces between supergranules. Simon and Leighton (**14**) found that the boundary between supergranulation cells, where the motion is downward, is associated with enhanced magnetic fields. Theoretical discussions of the concentration of fields at the cell boundaries were given by Weiss (**15**) and Clark (**16**).

Filaments, prominences and corona

Chvojková (**17**) discussed a filamentary model consisting of a magnetic arch filled with charged particles supported at a high level by diamagnetic repulsion, as in a mirror device. If the supporting force is sufficiently strong, a slight variation of conditions may lead to an eruption. An inverse process, in which a slight disturbance leads to a 'dumping' of trapped particles, was suggested by Elliott (**18**) as a possible explanation of solar flares.

Interpretations of arched prominences as bundles of lines of force were also suggested by Ivanchuk (**19**), Doherty and Menzel (**20**), and Jefferies and Orrall (**21**). Of these, Jefferies and Orrall interpreted prominences as loops along which flare plasma is returned to the photosphere; Doherty and Menzel discuss primarily the cooling of filaments with a longitudinal magnetic field. Howard and Harvey (**22**) found observationally that, whereas dark fibrils are perpendicular to the isogauss lines of the horizontal field, filaments are parallel to these. This suggests a filamentary model closer to the earlier models of Kippenhahn and Schlüter or of Dungey; a development of Dungey's model was discussed by McLean (**23**). Kink instability was invoked by Hirayama (**24**) to explain prominence blow-offs. Magnetic 'hills' in the chromosphere above active regions, with force-free fields, were suggested by Iospha *et al.* (**25**).

The magnetic field in the corona has mainly been studied through the polar rays, regarded as indicators of field directions. Kopecký and Suda (**26**) analysed the variation of direction of the rays with latitude and height; Saito (**27**) and Stoddard and Carson (**28**) interpreted the field as that of a bar magnet of variable length, the length being greatest near sunspot minimum. The connection of the coronal field with that at the surface was studied by Harvey (**29**) and by Pikelner (**30**), but in general terms only; its connection with that of the solar wind has likewise been studied in general terms only, e.g. by Mustel (**31**), van Heuvel (**32**) and Mogilevsky (**33**).

The effects of a magnetic field in limiting motions and wave dissipation in the chromosphere have been considered respectively by Kleczek (**34**) and by Livshitz *et al.* (**35**). Chromospheric and coronal heating by magnetosonic waves were considered by Pikelner and Livshitz (**36**), Lüst and Scholer (**37**) and Parker (**38**). Meyer (**39**) interpreted certain fast disturbances observed by Moreton as chromospheric effects of magnetosonic waves propagated in a channel between corona and chromosphere.

Sunspots; solar cycle

Model calculations of the field due to sunspots have been made by Schmidt (**40**) and Oster (**41**).

A number of papers on the solar cycle have already been mentioned in the section on Field Structure. Chvojková (**42**) developed Babcock's theory of the cycle, in Kopecký's modified form, in discussing the generation of toroidal fields at sunspot latitudes; see also Tuominen (**43**). Godoli applied the Babcock-Kopecký theory to the law of sunspot drift with latitude (**44**). Kopecký (**45**) attempted to explain a possible 80-year cycle on the basis of a theory similar to that for the 11-year cycle. Iroshnikov (**46**) proposed an oscillatory instability in the presence of differential rotation and a magnetic field to explain the 11-year cycle. Kozhevnikov (**47**) suggested that spot fields, before their convection to the surface, are concentrated near the bottom of the convection zone, not distributed throughout that zone. Romanchuk (**48**) attempted to explain solar fields by the interplay of fields in the corona and the photosphere.

Many sunspot observations have been concerned with motions near the spots. Moreton and Gopasyuk (**49**) found that in the September 1963 spot group the relative motion of spots was in the direction of the transverse field. Gopasyuk (**50**) found that plasma inflow occurs at photospheric levels when the spot field is increasing. Schröter (**51**) inferred from observations that the Evershed effect is due to the upward motion of bright material, and the downward motion of dark, in fine structures. Livshitz and Pikelner (**52**) discussed possible diamagnetic ejection from sunspot regions. Bumba, Kopecký and Kuklin (**53**) considered the life history of a sunspot, emphasizing the fine structure and the relation to supergranulation and pores. Kopecký and Kuklin (**54**) applied formulae for the conductivity of an ionized gas to the time of decay of a sunspot; it should be noted, however, that the results are very sensitive to the level at which decay is supposed to occur.

Deinzer (**55**) gave a magnetohydrostatic theory of sunspot equilibrium, similar in spirit to the earlier theory of Chitre; he used a mixing length whose ratio to the scale height is smaller in the spot than outside, because of magnetic inhibition of convection. Gough and Tayler (**56**) obtained sufficient criteria for the stabilization of thermal instability by a magnetic field; they applied this to sunspots, confirming the large reduction in heat convection. Danielson's Stratoscope observations (**57**), however, suggest that small-scale convection is present even in a spot umbra.

Solar flares

Many observers have stressed the intimate connection between solar flares and filaments. Smith and Ramsey (**58**) pointed out the changes in filamentary structure just before and at the commencement of a flare, and found that flares could set filaments oscillating. Kleczek (**59**) found that loop prominence systems develop from flares, apparently as a result of the propagation of flare particles along nearly stationary field-lines. Possibly a similar transmission along field-lines may be responsible for the observation by Moreton and Severny (**60**) that flares first brighten at two points on opposite sides of the line where the vertical field vanishes. Haurwitz (**61**) suggested that a loop-like field, as revealed by dark filaments, was essential for flare acceleration of electrons to high energies.

Theories of flares are manifold. They mostly rely on magnetic instabilities – exceptions are the theory of Hunter (**62**), which supposes shock waves to be generated in the chromosphere by a thermal instability, and that of Jacobsen and Carlquist (**63**), which relies on a circuit interruption more appropriate to laboratory discharges than to solar plasma. Sakurai (**64**) assumed a collapse of a magnetic field due to changes in the pressures exerted on a magnetic tube by the surrounding plasma; his discussion is, however, mainly descriptive. Kawabata (**65**) thought in terms of the collapse of a coronal condensation after the ejection of a cloud which becomes magnetically isolated as a consequence of suprathermal turbulence near a neutral point. Wentzel (**66**) interpreted a flare as arising from the collapse of an unstable chromospheric region towards a surface of minimum but non-zero field.

The main difficulty of magnetic flare theories is to find a sufficiently rapid mechanism for converting magnetic energy into heat. Flows near a neutral line leading to the breaking of field-lines have been considered by Syrovatsky (**67**). Two other theories deserve a special mention. The first is that of Petschek (**68**), which seeks to provide the necessary dissipation through standing hydromagnetic shock waves. Shock waves almost certainly do accompany flares; however, Sweet and Green (**69**) give arguments suggesting that Petschek's flare picture involves internal inconsistencies, and needs at least to be seriously modified. The second is that of Sturrock and Coppi (**70**), in which gravitational instability of gas supported by a sheared magnetic field sparks off a more violent instability of plasma broken into fine filaments. They claim that this mechanism can give the observed time-scale of rise to flare maximum, but so far it has not been studied in full detail.

Flares emitting solar cosmic rays were found by Warwick (**71**) to be those in which initially there is a steep magnetic gradient. Wentzel (**66**), on the other hand, suggested that the distinguishing feature of such flares might be their occurrence at a high level. The mechanism of generation of the cosmic rays is possibly Fermi acceleration between converging shocks—cf. Sakurai (**72**)—but discussions of the acceleration process do not in general go far into detail.

INTERPLANETARY PLASMA; THE SOLAR WIND

General properties

The Proceedings of the 1964 Solar Wind conference (**1**) gives a good general introduction to present knowledge about interplanetary plasma.

Recent work has confirmed that the solar wind blows all the time, but with substantial variations in velocity, density, and 'temperature'. Electron-densities quoted are 3 to 10 per cm^3, with peaks up to 25 per cm^3 (**73, 74, 75**). Velocities are found to fluctuate between 300 and 800 km s^{-1} ((**74, 75**); see also (**181**)); their directions may deviate 5 to 10° from the radial (**76**), mainly in the sense indicating partial co-rotation with the Sun. The temperature of thermal motions parallel to the magnetic field may be five times that of the thermal motions perpendicular to it (**76**). The magnetic field is, on an average, about 5 γ in magnitude, directed at about 45° to the solar direction (**77, 78**); it also appears to possess a persistent component perpendicular to the ecliptic, which is very difficult to comprehend (**79**). (These results all come from satellites in the Earth's neighbourhood, i.e. not far from the ecliptic.) A recent account of the normal form of the solar wind is that of Coleman *et al.* (**80**).

Although the direction of the magnetic field is, apart from random fluctuations, reasonably constant and along the expected spiral, it reverses in sign from time to time, corresponding to the polarity of the region with which it is linked. Wilcox and Ness (**81**) found evidence of a persistent magnetic structure, co-rotating with the Sun, in which the field was directed alternately towards and away from the Sun, each for some days on end; cf. also Coleman *et al.* (**82**), Ness (**83**). Ness and Wilcox (**79**) and Bumba and Howard (**183**) have also been able to relate the field with that at the centre of the Sun's disk 4–5 days earlier; this is the field of a large magnetic region, not the local field of sunspots. In this connection, see also Mustel (**31**), whose conclusions are somewhat different.

Co-rotation of the field pattern does not by itself imply rotational motions; the familiar garden-hose effect leads to a co-rotating pattern even if the motion is wholly radial. However, the plasma motion near the Sun must have a share of the solar rotation—cf. the model by Stern (**84**). The results of Wolfe *et al.* (**76**) and of the Vela experimenters suggest a corotational velocity of order 15 km s^{-1} near the Earth.

Theory of the solar wind

Parker (**85**) has considerably developed his theory of the solar wind, applying it also to stellar winds. He has usually considered a hydrodynamic spherical expansion of a high-temperature corona up to supersonic velocities, the temperature being maintained at a high value by heat conduction. Magnetic fields and rotation were usually not considered. However, in one paper (**86**) he considered expansion along magnetic filaments rooted in local areas of the solar surface. The filaments were conceived as expanding, with increasing distance from the Sun, to fill the whole of space, and to become tangled together beyond about 1 A.U. by Helmholtz instability.

Spherical expansion was also discussed by a number of other authors (**87**), usually with neglect of viscosity. Whang, Liu and Chang (**88**) found that viscosity leads to a much reduced asymptotic velocity of outflow. Meyer and Schmidt (**89**) showed that a radial magnetic field greatly reduces the effects of viscosity. In any case, the effects of viscosity and thermal conduction, as well as the anisotropy due to a magnetic field, are so great beyond (say) 10 $R_\odot$ that a normal hydrodynamic treatment becomes suspect. However, Brandt and Cassinelli (**90**), treating the wind as an exospheric problem, obtained results differing not too widely from those of the hydrodynamic treatment. Kalinin and Mogilevsky (**182**) have developed the hypothesis that M–region disturbances arise from chains of independent elements ('plasmoids') generated in active regions of the Sun, and travelling radially through the quiet solar wind, each carrying its own force-free field with it.

A corotating magnetic field considerably complicates the mathematical problem. In the first of two papers (**91**), Pneuman gave a picture of the field in meridian planes at solar minimum as roughly dipolar (at least at high latitudes) out to several solar radii, then becoming radial where the flow is dominant. In his second paper he suggested that there is corotation of the outflowing material out to about 3 $R_\odot$. King and Carovillano (**92**) considered the interaction between the magnetic field and the angular momentum of the outflowing gas; Brandt (**93**) considered the corresponding braking of the solar rotation, finding a braking time of 7×10^9 years if the material corotates partially to 1 A.U. In a more detailed discussion, Weber and Davis (**94**) considered a two-dimensional model representing the flow and field in the equatorial plane, paying special attention to the points where the Alfvén velocity is reached. They estimated that the degree of corotation near the Sun, though with less than the solar angular velocity, still gave a braking time of 5×10^9 years.

Shock waves

Interplanetary shock waves can arise when a faster solar stream overtakes a slower (especially after a flare) or when the solar wind impinges on a barrier. Such shock waves are collisionless; the plasma particles can be regarded as forming a normal gas only insofar as they are tied together by the magnetic field.

Sturrock and Spreiter (**95**) have given an explanation of a negative impulse following immediately after the initial positive impulse at the sudden commencement of a geomagnetic storm, in terms of a pair of shock waves due to ejected flare plasma. Colburn and Sonett (**96**) suggested similar shock pairs at the edge of an M-region stream. Simon and Axford (**97**) obtained a similarity solution of the hydromagnetic equations which involved such shock pairs.

The bow shock at the Earth's magnetosphere fluctuates with the strength of the solar stream. Its reality is best shown by the sudden increase in field-strength, accompanied by a transition to a disordered field, as the shock front is penetrated by the plasma (**77**, **98**). A hydromagnetic discussion of the shock front has been given by Lees (**99**); see also Obayashi (**100**), Sozou (**101**) and Spreiter, Summers and Alksne (**102**). A number of possible instabilities have been suggested as contributing to the highly disturbed nature of the region inside the shock front (**103**).

'Spikes' of energetic electrons (energies > 30 keV) are observed near the bow shock (**104**). These are believed to be generated locally by a Fermi mechanism between converging shock fronts, e.g. when trapped between the bow shock and an approaching wave ((**105**), and (**2**), p. 105). Similar energetic electrons are also found in the tail of the magnetosphere (**106**); these may be those accelerated in the bow region, carried down into the tail, but may also be accelerated in the neutral sheet of the tail ((**2**), p.147). Apparent variations of electronic energies behind the bow shock are sometimes to be interpreted in terms of diffusion (**107**) or diamagnetic effects (**108**).

Interaction with the Moon, planets and comets

The tail of the magnetosphere extends downstream from the Earth for a distance of at least 50–60 Earth radii ((**109**), and (**1**) p.231). The Earth's magnetosphere can only in a restricted sense be regarded as the prototype for magnetospheres of the Moon, planets and comets, which often possess no appreciable magnetic fields of their own.

A lunar magnetosphere was inferred by Ness *et al.* (**77**, **110**) from observations of an enhanced irregular magnetic field, apparently in the Moon's wake. Aronowitz and Milford (**111**) worked out how the magnetic shielding of the Moon's surface from the solar wind would vary with the lunar magnetic moment. However, there is no evidence of any appreciable lunar field, and the solar wind is likely to strip away any appreciable atmosphere (**112**). As Gold pointed out ((**1**), p. 381) the lunar magnetosphere is likely to be formed from lines of force of the solar wind, hung up on the Moon because of its finite conductivity.

Venus and Mars do not appear to possess magnetic fields, and no appreciable magnetospheric effects have been observed for either. The radio emissions from Jupiter strongly suggest that it has a magnetic field. No direct observation of its magnetosphere is at present possible; but the correlation of variations in its radio emission with the position of Io suggests some influence of Io on the plasma round Jupiter, related in a highly directional manner to the magnetic field ((**113**), pp. 134, 137 and 141).

Cometary tails provide our strongest evidence of a solar wind at high solar latitudes. An appreciable part of the interaction between the solar wind and cometary tails is hydromagnetic ((**1**), pp. 355, 365, and 373). However, emission of plasma by the comet may also lead to a (collisionless) bow shock in the front of the comet, and a magnetosphere with some features in common with that of the Earth (Biermann *et al.* (**114**), Axford (**115**), Marochnik (**116**)).

COSMIC RAYS

Cosmic rays and the solar wind

General accounts of the interaction of cosmic rays with the solar wind have been given by Anderson ((**1**), p. 53) and Quenby ((**2**), p. 3).

In addition to flare particles, protons of energy 1 – 100 MeV appear to be emitted continuously by the Sun, and to be guided in co-rotating magnetic fields (Fan *et al.* (**117**)). They are strongly collimated along the magnetic field, presumably because of decreasing pitch angles as the magnetic field decreases. They come from a mean direction midway between those of the Sun and of the magnetic field. Rapid intensity-oscillations in them suggest waves in the solar wind (see also Bryant *et al.* (**118**)).

Sakurai (**119**) divides solar protons into those propagating direct from the Sun and those trapped in plasma clouds. A better model for energetic particles is to regard them as propagating along the lines of force, but subject to magnetic scattering. The scattering may be due to shock waves (**120**), or to magnetic irregularities of dimensions about 10^6 km (**121**). Scattering leads to diffusion which, because of the magnetic constraints, is strongly anisotropic; many of the characteristics of solar cosmic ray events can be accounted for adequately by models which take this anisotropy into account (**122**). The diffusion coefficient can be related to the (observable) magnetic field variations (**123**). The different diffusive properties of particles of different mass may lead to differences in composition of solar cosmic rays; but in general the composition of solar cosmic rays is similar to that of normal solar gas ((**1**), p. 215, and (**124**)).

Galactic cosmic rays – for the moment this is taken to refer to all cosmic rays coming from outside the solar system – are affected by scattering (**125**) and by the corotation of the interplanetary magnetic field (**126**). The latter is calculated as producing a diurnal variation of amplitude 0·6%, in good agreement with observation ((**2**), pp. 26, 213 and 231). While within the solar stream cavity, cosmic rays may undergo appreciable losses in energy through Fermi deceleration between diverging wave fronts (Parker (**127**)). This may contribute to explaining the observed cosmic-ray modulation in the solar cycle; the intensity at the Earth is 5% less than that in interstellar space at solar minimum, and may be 20% less at solar maximum ((**2**), pp. 97, 261 and 292).

Cosmic rays give information as to the size of the cavity occupied by the solar wind in interstellar space. To produce the observed scattering of solar cosmic rays, a radius of only 1·5–2 A.U. is required (**128**). However, to produce the long-term modulation, a radius above 20 A.U. may be needed ((**2**), pp. 3, 173 and 180); the precise value is uncertain, depending on factors like the anisotropy of cosmic ray diffusion, or the friction between cosmic rays and the solar wind.

Origin of cosmic rays

As the results for the solar wind indicate, particle acceleration to high energies is a normal process in the universe. Among the mechanisms studied in the period under review are the following. Hayakawa *et al.* (**129**) surveyed the usual electromagnetic mechanisms (Fermi, betatron); Wentzel (**120, 130**) considered Fermi acceleration between shocks; Tsytovich (**131**) studied acceleration by plasma waves, including waves in supernovae; Colgate ((**2**), p. 112) invoked supernova blast waves; Sturrock (**132**) considered plasma waves, accelerating particles riding their crests; Finzi (**133**) invoked neutron stars; and Burbridge and Hoyle (**134**) considered explosions in the nuclei of galaxies. Supernova explosions appear to be the most commonly invoked, but even as regards these the mechanism of acceleration requires detailed study.

The seat of origin of non-local cosmic rays may be galactic (Ginzburg and Syrovatsky: (**135**) and (**2**), p. 53) or metagalactic (E. M. and G. R. Burbridge, (**2**), p. 92). One criterion used by Ginzburg and Syrovatsky for distinguishing between the two is the unobservability of any appreciable background flux of radiation from intergalactic space; however, this is not altogether decisive, as the radiation would come from cosmic ray electrons, not heavy particles, and equipartition of magnetic energy with the other forms of energy present is assumed. Another criterion is the ease with which cosmic rays can enter or leave the Galaxy. Ginzburg (**136**) suggested that where cosmic rays exit from a strong field into a weak, instabilities tangle the field and lead to an effective closure; thus cosmic rays from any galaxy tend to be pent in that galaxy. However, this is not the only possibility; Parker ((**137**) and (**2**), p. 126) suggested that cosmic rays will inflate the galactic field into a large-size halo from which they can ultimately escape.

Because of the intimate connection between cosmic rays and X-rays, X-ray observations may ultimately help to decide the location of cosmic ray sources. The possible mechanisms of generation of X-rays have been considered by Gould and Burbidge (**138**) and Hayakawa *et al.* (**139**); other papers on radiation due to high-energy particles are given in (**140**) and (**2**), pp. 68 and 132.

STELLAR AND INSTELLAR FIELDS

Magnetic stars

Little work on magnetic stars can be reported here. Ledoux and Renson (**141**) have reviewed the properties of such stars, with special attention to magnetic variables. Ledoux (**142**) has suggested an explanation of magnetic variation in terms of the control of unstable *g*-modes of oscillation by rotation. Steinitz (**143**) has found possible periods of magnetic variation for two stars regarded by Babcock as irregular; but Renson (**144**) has pointed out the danger of spurious periods due to statistical fluctuations. Fowler *et al.* (**145**), giving up the idea of neutron reactions due to surface electromagnetic acceleration, now suggest the anomalous abundances in magnetic stars to be due to internal nuclear reactions. Smith (**184**) has considered the decay of toroidal magnetic fields, obtaining decay times up to $3 \cdot 79 \times 10^9$ years as maximum.

The generation of stellar fields has been considered by Mestel (**146**); of the three mechanisms discussed (fossil, battery and dynamo) he regards the fossil theory as offering the best hope of explaining strongly-magnetic stars. The battery theory (Biermann's currents due to non-uniform rotation) has been considered by Roxburgh and Strittmatter (**147**), who derived toroidal fields of order 3×10^6 gauss in rapidly rotating stars in favourable circumstances. The fossil theory was considered by Pneuman and Mitchell (**148**), who obtained a reasonable field for the Sun by assuming that the field was not frozen into the contracting gas cloud until a temperature of 1500°K was reached. Steenbeck *et al.* (**149**) have discussed a dynamo mechanism based on the interaction of a turbulent fluid motion with a field with non-vanishing mean value. In both this theory and one by Csada (**150**), based on eigenfunction analysis, it is not clear how far the results may be affected by a 'rounding-off' approximation.

Galactic and intergalactic plasma

A review of observations of magnetic fields in the Galaxy has been given by Davies ((**2**), p. 55); see also papers listed under (**151**). The field as seen from the Sun is mainly along the local spiral arm, though with superposed irregularities; fields at high positive galactic latitudes may be oppositely directed to those at other latitudes. The magnitude of the field in clouds is probably between 5×10^{-6} and 10^{-5} gauss.

The opposition of a magnetic field to gravitational collapse is of interest at a number of levels. Mestel (**152**) considered the contraction of a prestellar cloud, assuming strict flux freezing; inside the cloud his results were in general agreement with those obtained from the virial theorem, but outside he found a layer of near discontinuity ready for field reconnection. Strittmatter (**153**) considered contraction of a mass of gas when its magnetic field is too strong to permit radial contraction; he found that, though initial contraction along the lines of force was possible, this led to little improvement in the ability to form stars. He also investigated how far the Jeans criterion for gravitational instability should be regarded as affected by a magnetic field.

On a larger scale, Setti (**154**) argued that the gravitational field of stars will stabilize a helical magnetic field in a spiral arm. Parker (**155**) pointed out that a magnetic field confined to the galactic plane by the weight of plasma would be subject to Rayleigh-Taylor instability; this would concentrate gas into pockets (clouds) suspended in the field. Gershberg (**156**) considered the possibility that intergalactic 'bridges' might be explained by pinching due to the twisting of lines of force.

The interplay of magnetic fields, rotation and gravitational contraction is often invoked in connection with the formation of galaxies and quasi-stellar sources. Piddington (**157**) explained the difference between normal and radio galaxies in terms of the angle θ between the initial directions of the field and the axis of rotation. Featureless flat disks are produced if θ is small; if it is nearly a right angle, the field is wound into a spiral form, from which ultimately it buckles explosively to produce a radio galaxy. In a quasar there are alterations of field-winding and explosive acceleration. Pikelner (**158**), who developed a similar theory, pointed out the possibility of field reversals in a single spiral arm for intermediate values of θ. He stressed the possible effects of instabilities at surfaces of field reversal. Layzer (**159**), in a less developed theory of similar type, emphasized the role of magnetoturbulence in tangling the field lines, which afterwards straighten explosively, leading to collapse. Bardeen and Anand (**160**) criticized Layzer's theory on the ground that the mass that can be temporarily stabilized against collapse by magnetoturbulence is much reduced when one takes account of supersonic dissipation. Sturrock (**161**) sought the source of energy of a quasar in a flare-like snapping of the field-lines connecting a contracting mass to the surrounding plasma.

Ginzburg and Ozernoy, in a number of papers (**162**), examined the possibility that quasars are due to contraction which approaches the relativistic limit. The contraction reinforces the magnetic field, though in the later stages the field may with draw towards the Schwarzschild surface. The collapse was supposed to be halted by a regular circulatory motion in the magnetic field; this leads to a configuration called a magnetoid, which was identified as a quasar. Shock waves and ejected matter were regarded as responsible for most of the radiation. An earlier paper by Kardashev (**163**) also considered contraction towards the relativistic limit.

Other papers on explosive phenomena are as follows. Kulsrud *et al.* (**164**) considered the explosion of a supernova into the interstellar field, piling up lines of force before it which, through Rayleigh-Taylor instability, produce strong filamentary fields. Pikelner (**165**) discussed the formation of arms in a barred spiral after an explosion which compresses the lines of force. Chvojkova (**166**) suggested that in a planetary nebula there are intense plasma jets from the poles of the central star, which are guided towards the equatorial plane along lines of force; the streams may build magnetic arches or unwinding spirals. Wentzel (**167**) applied Petschek's mechanism for relinking magnetic field-lines to the formation, acceleration and detachment of interstellar clouds.

GENERAL

Alfvén and Elvius (**168**) have further developed the suggestion that the universe is composed of 'ambiplasma', consisting of equal amounts of matter and antimatter. These are supposed to be segregated in regions separated by 'Leidenfrost' layers. The present expansion of the universe is ascribed to radiation pressure due to particle annihilation in an initial denser universe. Chiu (**169**) suggested, however, that the large initial annihilation of matter would lead to a present background radiation-density greater than is observed.

Kaplan and Tsytovich prepared for me a detailed report on recent Soviet work on high-frequency processes in plasma. For the reasons noted in the Introduction to this report, no details (other than bibliographical) of this work can be given. It refers to the generation of plasma waves by streams of fast charged particles (**170**), turbulence (**171**) or radiation (**172**). Parker (**173**) has also considered possible waves in a gas composed of a superposed cosmic ray plasma and a normal one, and Tidman (**174**) has discussed the damping of plasma motions through interaction with cosmic rays.

Certain other papers whose interest is mainly mathematical are similarly briefly mentioned. These are on wave propagation (**175**), stability of a fluid layer (**176**), a polytropic atmosphere (**177**) or a fluid cylinder (**178**), transport processes in a plasma (**179**), and fire-hose instability (**180**).

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