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AERODYNAMIC PHENOMENA IN STELLAR ATMOSPHERES
SUPPLEMENTARY BIBLIOGRAPHY COVERING THE PERIOD 1960-64

prepared by

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Note: This bibliography is intended to supplement that presented in Technical Note 30 of the National Bureau of Standards

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University of Colorado
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FOREWORD

In 1960, a number of astronomers collaborated to prepare a working bibliography on papers which had appeared in the astronomical literature covering aerodynamical phenomena in stellar atmospheres, covering roughly the period 1920–60. This bibliography was intended for particular use as background for the Fourth Symposium on Cosmical Gas Dynamics, which was the first held on Aerodynamical Phenomena in Stellar Atmospheres, at Varenna, Italy, in August 1960. The foreword to that bibliography, whose publication was kindly supported by the National Bureau of Standards as Technical Note No. 30, should be consulted for further background.

In preparation for the Fifth Cosmical Gas Dynamics Symposium, which is the second in the series on Aerodynamical Phenomena in Stellar Atmospheres, to be held at Nice in September 1965, it seemed useful to bring the earlier bibliography up to date. This work has been carried out by Mr. Stuart Jordan, of the JILA staff, with the kind collaboration of Drs. Kaplan and Pickelner on material published in the USSR. Its preparation has been supported by the Joint Institute for Laboratory Astrophysics, as JILA Report No. 25.

These Symposia on Cosmical Gas Dynamics have been initiated and sponsored by the International Astronomical Union and the Union of Theoretical and Applied Mechanics, to promote the collaboration of aerodynamicists and astronomers on problems of common interest. It is our hope that these bibliographical compendia will help in delineating the astronomical areas.

Boulder, November 1964

Richard N. Thomas
THE SUN


The kinetic theory for the escape of planetary and stellar atmospheres developed by Stoney, Jeans, and others is generalized and applied to the solar corona and the interplanetary gas. This approach is contrasted with the use of hydrostatic equilibrium and the equations of heat conduction (Chapman) and with the use of the hydrodynamic equations of motion (Parker). Chapman's approach is criticized for yielding a too high value for the mean particle energy at the earth's orbit. Parker's approach is criticized for what the author feels to be too great an expansion velocity for the "solar wind." The theory developed here yields values for the mean kinetic energy per particle, electron density and mean expansion velocity as a function of distance from the sun.


From an examination of high-quality stratoscope photographs of solar granulation, the author identifies low-contrast regions which seems to persist for periods longer than 10 minutes and small-scale regions which seem to evolve with the normal granulation pattern with correspondingly shorter periods.


The first part of the paper investigates the singular properties of the solutions of the hydrodynamic equations and argues that the only steady state solution appropriate to the solar corona is the critical one which yields supersonic (500 km/sec) expansion at infinity. The second part of the paper shows that the solution obtained with the classical evaporation theory of Jeans, et al., is incorrect due to the erroneous assumption in the evaporation theory that evaporation takes place from the top of a static atmosphere.


The local Doppler shifts of several solar absorption lines were determined at various positions on the solar disk. Analysis yielded an average value of the random turbulent velocity to be 0.33 km/sec for elements with an average diameter of 5.5 seconds of arc (4000 km). However, the values of the random turbulent velocity and other characteristics showed systematic differences between weak and strong lines. Also, near the limb all the measured lines had smaller r.m.s. velocities than toward the center. This suggests that large scale motions may decrease as one goes "higher" or further out in the photosphere. The analysis also suggests that a rising element of the atmosphere is followed by a falling element in the same region.

The basic purpose of this paper is to show that observational knowledge of the temperature and density of the solar corona, both near its base and at the earth's radius, suggests that the outer corona expands hydrodynamically into interplanetary space. Theoretical evidence from the hydrodynamic equations is that the observed temperatures and densities in the solar corona near the sun do require and account for the observed supersonic interplanetary expansion of the corona. The author argues in favor of all main-sequence stars later than class F to possess stellar winds in analogy with the solar wind. In the appendix, there appears an outline of the theory of hydromagnetic heating of the solar corona predicting an ion thermal velocity in a hydromagnetically heated atmosphere the same order of magnitude as the hydromagnetic wave velocity. This prediction is in agreement with observed coronal temperatures.


The ionized interplanetary gas is viewed as an outer extension of the solar corona and is discussed using the equations of hydrodynamic motion, continuity, and the first law of thermodynamics with heat conduction. This treatment allows a solution in which both the expansion velocity and the density vanish at infinite distance. The results agree well with the evaporation theory of Paper II close to the sun but not out at distances the order of one astronomical unit. The author concludes that we should expect a solar "breeze" with velocity of several kilometers a second near the earth's orbit in contrast to a solar "wind" with velocity of several hundred kilometers per second. For such a solar wind, the author argues that there must be some accelerating mechanism in the corona for which he finds no evidence.


A shock wave model proposed by both Kahn and Parker for the collision of the solar wind with the ionized gas around the earth is re-evaluated in the light of recent developments in plasma stability theory. It is shown that the instability which was supposed to arrest the counterstreaming of the ions and to transfer much of their kinetic energy to the electrons is absent in many important cases. For example, only if the velocity of the solar wind exceeds a very high value of 1000 km/sec or so, does it seem likely that the electrons will acquire the required energy. Other plausible shock structures proposed by the time of writing are criticized.


The article is the thirteenth Henry Norris Russell Lecture of the American Astronomical Society. It represents a very lucid review of the history of convective energy transfer in stars beginning with Emden's work early in the century. A summary of the mixing length theory in its current form and of the laminar mode approach appear.
There is a discussion of how the laminar mode approach can provide insight into the behavior of small turbulent elements and how one can analyze the "overshoot" of turbulent elements from a convective region into a region in radiative equilibrium. The implications of these considerations for wave heating of the solar chromosphere and corona are discussed.


It is shown that type IV emissions in the frequency range 25-250 Mc/sec is closely associated with a type II burst preceding it. The source of the emission is situated high in the corona and moves with velocities of more than 1000 km/sec. A possible mechanism, already advanced by Boischot and Denis, is synchrotron emission from high-energy electrons spiraling in a "broken" magnetic field which is carried to appropriate heights in the corona by a cloud of hot gas preceded by a shock front which, presumably, excites the type II burst.


A time sequence of high-definition photographs of the solar granulation was obtained on a Stratoscope flight. The correlation function in time for the photospheric intensity variations was found to be well represented by a simple exponential decay with a time constant of 6.27 minutes. If the average lifetime of granules is defined as twice the time interval in which the correlation drops to half, this lifetime is found to be 8.6 minutes.


It is shown how sound waves can be trapped in the upper photosphere due to the temperature inversion, and that a pattern will be created with a periodicity of approximately 5 minutes, with distortions of a region of about 2250 km in length. This suggests a 5 minute periodicity in the fine structure of the sun.


Sound waves generated in the hydrogen convection zone are thought to be the main source of energy for heating the chromosphere and corona. These waves become increasingly magneto-hydrodynamic in character as they move out due to the inverse density gradient. Dissipation is attributed to shocks formed by these waves. The picture is completed by thermal conduction downward and slow and Alfvén mode propagation upward from the upper chromosphere where major shock dissipation and shock wave interactions are predicted. The plages and spicules seen at the solar limb are both interpreted, according to this theory, as regions of high magnetic field and slow mode disturbances along magnetic lines of force, respectively.


Profiles of many lines for chromospheric spicules, including the H and K lines of CaII, are investigated to determine the line broadening
mechanism. The analysis tends to confirm an earlier suggestion that
the CaII lines are broadened, in part, by a macroscopic motion of the
ions not shared by the neutral atoms and that this additional velocity
may arise from an interaction between the systematic spicule motion
and the magnetic lines of force.

A Statistical Photometric Analysis of Granulation across the Solar

Stratoscope granulation photographs are analyzed to yield ampli-
tude distributions, power spectra, brightness contrasts and related
quantities for solar granulation, using a statistical procedure which
differs somewhat from that of Schwarzschild and which yields somewhat
different results. The two methods should be compared, as they have
considerable bearing on the degree of confidence with which one asso-
ciates the observed granulation with convective elements after
the theory of Böhm-Vitense. Generally speaking, Edmond's conclusions are
more tentative on this question, particularly regarding the large-
scale limb granulation (θ > 70°) which he feels may not represent
convective elements.

Velocity Fields in the Solar Atmosphere. I. Preliminary Report;
1962.

Velocity fields in the solar atmosphere have been detected and
measured by an adaptation of a technique previously used for measuring
magnetic fields. A partial analysis of data obtained during summers
of 1960 and 1961 yields various results. Large cells are found dis-
tributed almost uniformly over the solar surface with typical diameters
of 1.6 × 10⁴ km, spacings between centers of 3 × 10⁴ km, lifetimes of
10⁴ - 10⁵ sec and r.m.s. velocities of horizontally outflowing (from
center to edge of cell) material of 0.5 km sec⁻¹. There is a similari-
ity in appearance to the CaII network associated with spicules. The
cells are believed to represent large scale convective motions which
originate at relatively great depths in the sun and overshoot the upper
boundary of the hydrogen convection zone so as to appear in the lower
chromosphere. Also, a distinct correlation is observed between local
brightness fluctuations and vertical velocities, with bright elements
tending to move upward with a r.m.s. vertical velocity of ~ 0.4
km sec⁻¹ nearly constant over their range, a period of 296 ± 3 sec,
an associated energy flux of 1.6 × 10⁹ ergs cm⁻² and a tendency to
grow in horizontal dimension as they move upward. The authors be-
lieve they are witnessing the manifestations of waves propagating into
and heating the lower chromosphere. Finally, observations of downward
motions appear to be concentrated in tunnels presumably following mag-
netic field lines and geometrically related to the CaII network.


This paper supplements a previous work by the same author (1961)
in which it was shown that the region of the temperature minimum in
the solar atmosphere (called the photosphere in both papers) could act
as a wave guide, trapping sound waves from both directions and channel-
ing their energy horizontally through the "photosphere" in a wave
pattern of 5-minute periodicity. The treatment was based on ray
theory. The present paper arrives at the same conclusion using wave
theory.

The "random turbulent velocities," $\xi$, of macroscopic motion in the solar atmosphere have been observed at the center of the disk from local Doppler displacements in 18 Fraunhofer lines. The measurements show a marked increase of $\xi$ with line strength and the correlation between the velocity shifts of one line with those of another diminishes steadily as the intensity difference between the two lines increases. Thus, there is a quantitative and qualitative variation in the velocity field with height. The center to limb variations in $\xi$ were determined from four Fraunhofer lines. Here, $\xi$ is nearly the same for all line strengths in the observed range. The authors suggest that the velocity field consists of a vertical component which increases strongly with height and a horizontal component independent of height.


This study is based on observed Doppler displacements in time sequences of spectrograms of selected lines from both the center and the limb of the solar disk. At the center, the velocity field consists mainly of vertical oscillations with r.m.s. velocities of 0.42 and 0.81 km sec$^{-1}$ at low and high levels, respectively. The periods of these oscillations cover the range 200-300 sec and seem to decrease with height. An autocorrelation study shows that the vertical velocity field is dominated by periodic oscillations with a strong peak in the time correlation at 300 sec. The study of time lags of oscillations between faint and strong lines suggests that these periodic oscillations are of a type intermediate between standing waves for the longer periods and progressive sonic waves for the shorter ones. There is some indication that individual oscillations are associated with individual granules. Near the limb, the observed motions are horizontal and consist of slowly changing velocities of $\sim$ 0.5 km sec$^{-1}$ in large surface elements on which are superposed smaller random velocities of short duration. The vertical and horizontal motions appear to be physically independent.


Cross correlation analyses between fluctuations in radial velocity and continuum brightness and between fluctuations in line equivalent width and both radial velocity and continuum brightness have been carried out for four sets of measurements of absorption lines near the center of the solar disk. The author concluded from his analyses that the level of microturbulence for dark areas on the disk should be increased by 4-10 per cent above current estimates with corresponding decreases for the bright areas. He advocates also a heterogeneous convection pattern at the sun's surface.
Asymmetries observed in the solar line profiles of the infrared oxygen triplet are studied in an effort to determine the degree of telluric influence in the development of asymmetries and to calculate the asymmetries, assuming their origin to be convective motion in the photosphere. Using a convective model derived from the Böhm-Vitense theory which embodies the overshooting of large elements beyond the top of the hydrogen convection zone, the author finds that the model of photospheric fluctuations which best gives the observed asymmetries corresponds to one recently derived by Edmonds.

A theoretical expression is obtained connecting parameters in the solar wind near the earth's orbit with parameters in the inner corona. The theory suggests a semiempirical model closely resembling the empirical model presented recently by Brandt. Near the earth, this semiempirical model yields expansion velocities of 200-400 km sec⁻¹ and a mean electron density of 1-5 cm⁻³.

Evidence is presented for a negative temperature gradient in the inner corona. The significance of the negative gradient to solar wind theories is discussed. It is concluded that the observed line broadening of certain coronal lines does not originate, for the greater part, from a macroscopic mass motion which one might associate with the solar wind.

Spectroscopic observations of the corona have important implications concerning its heating mechanism. The very small amount of gross Doppler shifts in coronal lines limits severely the types of non-thermal disturbances that may be postulated to heat the corona. These limitations are discussed in relation to the various wave modes proposed as heating mechanisms.

Edmunds' data on granulation contrast are interpreted in terms of solutions of the equation of transfer in non-uniform media. Although his results appear to be incompatible with an atmosphere in radiative equilibrium, there is a simple model representing emission from convective cells which reproduces the essential features of his results.

A calculation of the fundamental convective modes with horizontal scales in the range 500 km < λ/2 < 50000 km as well as their growth rate has been made for the solar case, using Böhm-Vitense's (1958) model of the hydrogen convective zone and incorporating a detailed
model of the radiatively stable photosphere and a schematic model of the lower parts of the chromosphere. The computations employ the linearized hydrodynamic equations and include the effects of radiative transfer. The conclusions include (1) a growth rate (hence degree of instability) which varies linearly with increasing wave number of the perturbation, (2) a very low \( \lambda/2 \ll 500 \text{ km} \) for "cut off" below which convective elements cannot exist due to radiative smoothing of temperature fluctuations, (3) restriction of modes of small horizontal scale to a vertically thin layer at the top of the convection zone, and (4) an increased distance of overshooting of the convective motion into radiatively stable layers for larger values of \( \lambda \) with modes of \( \lambda \geq 6000 \text{ km} \) penetrating a few thousand kilometers into the chromosphere.


Compressional acoustic waves in the chromosphere with motions assumed vertical and of standing-wave character, are studied with the aim of accounting for the 5-minute oscillations recently discovered by Leighton (1960) and confirmed by Evans and Michard (1961). For such waves the photosphere is found to provide an effectively solid bottom due to the temperature inversion with the attendant large density gradient, and the corona can provide a free, largely reflective surface. The temperature profile in the chromosphere required to provide a 5-minute period is not incompatible with current models, though this situation could change.


A new type of hydrodynamic-wave heating is proposed for the solar corona, supplementing current work with compressional acoustic and hydromagnetic waves. This new mode, the gravity wave, is shown to exhibit features permitting one to associate it with observed properties of the photospheric granulation. It is noted also that the compressional acoustic waves with frequency characteristic of the granulation cannot be readily transmitted through the upper photosphere. The author concludes that gravity waves may well be the dominant energy source for the corona and derives a model corona so heated which has a temperature of \( 10^6 \text{K} \) and a density of \( 4 \times 10^8 \text{ cm}^{-3} \) at \( 35000 \text{ km} \).


The solar magnetic field is twisted into an Archimedes spiral by the outflowing solar wind. This spiral must co-rotate with the sun in order for the solar wind to move radially without cutting magnetic lines of force. It is found that the solar magnetic field excludes solar winds with velocities less than 100 km sec\(^{-1}\).


A kinematical theory is developed for the r.m.s. magnetic fields produced by the interaction of turbulent eddies of given scale and
velocity with a large-scale weak magnetic field $B_0$. The theory is applied to the small-scale magnetic field generated by the solar photospheric granules in the observed, weak large-scale photospheric magnetic fields. The conclusion is that a weak field can be amplified by a factor of the order of $R^{1/4}/\ln R$ where $R$ is the magnetic Reynolds number. In the solar photospheric granules the amplification of the weak large-scale field will be by less than a factor of 10. Thus the magnetic energy appears to be far below the value required for equipartition with the velocity field.


A photometric study is described in which intensity fluctuations are determined at five wavelengths in $K_1$, $K_2$, $K_3$ and vertical velocity fluctuations are determined from displacements of two Fe I lines where the data were taken at 30 second intervals for more than half an hour at various positions on the solar disk. The results include an average period for well defined vertical oscillations of 273 sec with a r.m.s. velocity averaged over the disk of 0.203 km sec$^{-1}$ and a positive correlation between intensity variations and vertical velocity variations, although with a phase lag between maxima. It is pointed out that only 1 percent of the estimated flux of non-thermal energy from the convection zone is required to maintain the oscillations which are interpreted as standing sound waves.


From point-to-point variations in the central intensity, half-intensity width, equivalent width and Doppler shift of seven solar absorption lines of moderate intensity, the author concludes that the hotter photospheric elements participate in a more ordered motion than the cooler ones and there is a slight excess in the micro- as well as the macro-turbulent components of the cooler elements relative to the hotter ones.


Ledoux, Schwarzschild, and Spiegel have developed a Fourier decomposition of the turbulent, convective velocity field of the sun from the linearized hydrodynamic equations in which one can study the penetration of the unstable (laminar) modes into the stable fluid layers above and below the convection zone. This author has performed just such a study with particular emphasis on the convective overshoot below the convection zone. The results suggest strong penetration of modes of large horizontal scale which should be important near the lower boundary of the convection zone. Extensive mixing should occur, with important bearing on the low lithium abundance observed in the solar atmosphere.

Response of a stationary atmosphere to periodic radiative perturbations originating at the top of a convectively unstable region is studied with a set of non-linear first-order differential equations. An attempt to apply the results to the solar photosphere suggests that the observed increase of granulation contrast toward the solar limb cannot arise from radiative perturbations alone and that dynamical perturbations such as either a mixed gravitational and compressional wave or a mass flow associated with convection must be included. The calculations support the view that granulation near the limb manifests the excitation of acoustical-gravitational modes in the upper photosphere.


The r.m.s. magnetic field is computed from the hydromagnetic equations for a variety of velocity fields characteristic of the solar photosphere. It is shown that turbulent fluid motions will generate local r.m.s. magnetic fields a few times greater than the large-scale field strength in the photosphere. In the plage regions, where this large-scale field exceeds 20 gauss, it is shown that equipartition of energy between magnetic and velocity fields should occur. It is suggested that such equipartition may have something to do with plage formation.


From a systematic study of Doppler plates obtained during 1960 and 1961, the following conclusions emerge. Vertical oscillatory motions were found in all medium-strong lines observed. The average period of the motions, about 290 sec, is a well determined quantity for each spectral line. Slight, but real, variations between weaker and stronger lines suggest that the average period gradually decreases with increasing altitude in the line-forming regions of the upper photosphere. An oscillatory fluctuation of residual intensity was found in the cores of the stronger lines observed but not in the weaker lines or the core of Hα. The average period of the intensity fluctuations is somewhat shorter than that of velocity oscillations and also exhibits an apparent decrease with increasing altitude. The two oscillations bear a definite phase relation to each other, indicating they are physically connected. The observations are compared with expectations for a plane wave propagating vertically through an isothermal atmosphere with an altitude dependent, radiative relaxation time.


An analysis of observational profiles of six lines and two blends leads to a model of anisotropic, depth-dependent turbulence in the solar photosphere which can be resolved into radial and horizontal velocity components with the following properties: The
radial component decreases rapidly with height as does the tangential component which is of greater magnitude until the two become equal and form an essentially isotropic velocity field at a continuum optical depth \( \tau_{5000} \approx 0.01 \).


The hydrodynamic equations for the solar corona with no external heat source beyond a thin shell at the base of the corona were solved for the case of fast expansion where it was assumed that the corona is approximately 10 per cent ionized helium and that the Chapman expression for the thermal conductivity could be used everywhere. It was found that thermal conduction supplies sufficient heating to accelerate particles to the observed solar wind flux near the earth, if inner coronal densities are near currently accepted estimates and the coronal base temperature is near \( 2 \times 10^6 \) K. The stabilizing effects associated with viscosity and the solar magnetic field were examined also.


This note shows that the variation of period with height and the apparent transition from a progressive to a standing wave for oscillations of the solar atmosphere observed by Leighton and Noyes (1963) and Evans and Michard (1963) can be explained in the light of a theory developed by Lamb in 1908. However, the theory predicts a more rapid decay in the amplitude and a smaller increase in size of the elements with height than actually observed.


The equations governing the generation and propagation of waves in a compressible atmosphere are solved for both isothermal and nonisothermal cases and results of the latter are applied to the solar atmosphere. It is found that for certain regions in the solar atmosphere there exist bands of non-propagating frequencies which are highly suggestive of standing waves which may represent recently observed oscillations. It is also suggested that the large-scale horizontal motions observed in the "supergranules" create small-scale turbulence in the radiatively stable region of the atmosphere through a vertical shear effect and that this turbulence may be responsible for the observed negative correlation between brightness and vertical velocity in higher atmospheric layers.


It is assumed that the solar atmosphere is heated by the periodic passage of shock waves. A qualitative physical argument is advanced suggesting that the strength of the shock waves may remain approximately constant in the solar atmosphere. An atmospheric model computed by using this constant shock strength hypothesis gives fair agreement with current ideas on the gross
temperature distribution and average gradient in the solar atmosphere, but says nothing about the details of the distribution in the chromosphere where the sharp rise occurs.


In an effort to elucidate why coronal temperatures obtained from line profile measurements exceed those inferred from ionization theories, this paper considers the question of what non-thermal motions could occur in the solar corona. Generally speaking, the author seeks some form of microturbulence, defined here as those non-thermal motions of such randomness and scale that their spectroscopic effect is almost indistinguishable from thermal motion. That is, the line profiles are very nearly Gaussian. It is shown that line profiles are distorted from the Gaussian in a manner similar to what is observed if the matter is undergoing harmonic oscillations or radial flow in cylindrical structures, depending on detailed conditions along the line of sight. Such motions have already been proposed by other authors. Furthermore, it is pointed out that conditions in the corona tend to prevent motions of randomly moving gas aggregates and turbulence in the usual hydrodynamic sense. If one accepts coronal temperatures of $10^6$°K or less, the microturbulent velocities must be more than 20 km sec$^{-1}$. By a comparison of this value with that of like quantities in the photosphere and chromosphere where thermal velocities are also much lower, the author concludes that these microturbulent velocities are not excessive.


Existing methods of interpreting data on brightness fluctuations in the solar photosphere are compared with reference to their bearing on theories of solar granulation. In particular, the author compares his 'model' approach with a more strictly empirical approach due to Edmonds.


A fictitiously low value for the electron temperature may result from calculations involving two stages of ionization of a given element such as Fe if one fails to include the effect of macroscopic velocity fields. Thus a low electron temperature may result when there is an outward expansion of ions into a region of higher electron temperature.


Calculations of the convective growth rate are carried out for an inviscid, radiating, polytropic layer for two special cases. It is concluded that radiative transfer does not qualitatively alter the dependence of the growth rate on the horizontal wavenumber for convective modes of interest in the solar photosphere. The growth
rate appears to be a monotonically increasing function of the horizontal wavenumber with no radiative cutoff. This latter result is at odds with granulation observations.

Photographs of the solar disk in the near ultraviolet are discussed with regard to the apparent size and brightness contrast of photospheric granules in this spectral range. It is noted that an increased contrast appears when the granulation is observed in near ultraviolet, relative to photographs taken at longer wavelengths. No detailed explanation of the results is offered.

It is shown that one can predict a quantitative value for the energy of a type II solar radio burst in agreement with observation, from calculations of the efficiency of rf emission from longitudinal plasma oscillations and from charge separation considerations in collisionless plasma shocks. Application of the methods to the solar corona suggests the radio spectrum of the quiet sun may be nonthermal below 20 Mc.

A calculation of radio noise emitted by electrons moving in the strong stationary electric-field oscillations inside a shock wave moving through fully ionized hydrogen in the absence of a magnetic field suggests that type II solar radio bursts might be generated this way as a solar flare expands into the corona.

It is suggested that the corona at maximum phase is expanding and that the observed radial magnetic field results when localized fields near the surface are carried out into the corona by the expanding gas. The typical polar field at sunspot minimum could be caused by a consistent N-S asymmetry in the localized fields during the preceding maximum phase.

In an effort to clear up discrepancies between discordant values for the true r.m.s. brightness fluctuation in solar granules, the authors conclude that a comparatively low value of about 7 per cent is correct, attributing the higher values to an approximation in which Blackwell, et al., identify the granule diameter with one wave length, rather than half a wave length.

Viscous Damping of Hydromagnetic Waves in the Corona; Landseer-Jones; M. N., 122, 89, 1961.
It is suggested that proton-proton collisions are responsible for heating the solar corona above the transition region where one
might expect proton-neutral particle collisions to be important. The initial source of energy, dissipated by the proton-proton viscous mechanism, would be hydromagnetic waves generated at the top of the photospheric convection zone. If the frequency of the waves is $10^{-2}$ sec$^{-1}$, an estimate of the energy carried by them yields $10^5$ ergs cm$^{-2}$ sec$^{-1}$.

On the Center-Limb Variation of Granule Contrast; Giovanelli, R. G.; M. N., 122, 523, 1961
It is shown that the observed center-limb changes in granule contrast, and particularly the disappearance of granulation near the limb, may be due to foreshortening and finite telescope resolution. The difficulties of inferring the optical depth of the top of the granulation zone are discussed.

A process is described whereby the Sun's polar field can be built up from comparatively small-scale magnetic loops carried outwards by particle streams. The observed reversal of the general polar field may be carried by a reversal of the sense of those loops which straddle the solar equator.

This paper devotes one section to a discussion of prominences and their gross dynamical properties, as deduced from observations.

The CaII K line profile is found to have an anomalous broadening from a non-thermal velocity field in the spicules not shared by hydrogen and HeI. This velocity field of the CaII ions is tentatively identified with their interaction with magnetic fields.

The random turbulent velocity of macroscopic elements derived from root-mean square values of wave length shifts of several Fraunhofer lines is found to change with depth in the photosphere. It goes through a minimum at the level of formation of average lines and increases with depth for both strong and faint lines. No difference in the scale of velocity fluctuations could be found between faint and strong lines. There is, however, a scale difference between brightness fluctuations and features of the velocity field.

Certain non-permanent aspects of the motion of unstable systems are analyzed by the principle of maximum instability which is developed in a set of linearized equations in the first part of the paper.
From this point of view, a dynamical model of the solar convection zone comprised of a thin turbulent overlayer excited by a weakly unstable underlying zone is analyzed. The evolution of turbulent elements in this model is in qualitative agreement with some recent observations of the evolution of solar granules.


Time sequence photographs of high resolution spectra of the center of the solar disk are used in a statistical study to determine time variations in radial velocities from 6 "wiggly" Fraunhofer lines of various strengths and atmospheric levels. Brightness fluctuations in the continuum and at the centers of 2 lines have also been analyzed. The power spectrum of vertical velocities at upper photospheric levels is confined to a narrow range of frequencies peaked at 295 sec for average lines. The motions of selected strong and faint lines show phase shifts too small for sound waves, suggesting that they arise from transient initial stages of motions which decay towards standing oscillations. The statistical analysis supports the notion that sudden appearances of bright granules are the starting agents of vertical oscillations with further independent decay of the two features. A correlation of the brightness fluctuations in line centers with velocities in the same lines supports the idea that upper photospheric structures are due to hydrodynamic waves and not convection. There follows a brief discussion of the velocity field in the low chromosphere exemplified by the infrared CaII lines.


Employing a critical density condition on the trapping of mechanical waves originating at the top of the convection zone and propagating into the outer solar atmosphere, the author discusses the dissipation process and how knowledge of the mechanical dissipation yields useful information for obtaining the maximum coronal temperature, coronal density, coronal condensations and the height of the chromospheric Hα lines. He compares his model with some observational results.


The so-called mushroom structures of active chromospheric regions average 11000 km in height and have a diameter of 2000–3000 km. Their mean life is 10 minutes and their mean ascending velocity about 25 km/sec. On the solar disk, they appear as bright points or as microflares.


An intensive coronal condensation is analyzed. It had a duration
of more than 10 hours, ascended with a velocity of about 2 km/sec and reached a height of 100000 km at least. The condensation was accompanied by numerous prominences.


The author concludes that there is sufficient energy in the convective region of the lower photosphere to heat the sun's outer atmosphere without elaborating on the details of the energy transfer mechanism.


Higher convective modes and their rates of instability have been computed for the model of the solar hydrogen convection zone given by E. Böhm-Vitense (1958). The calculations are based on the linearized hydrodynamic equations, neglecting viscosity and radiative transfer. The computations cover the fundamental through the fourth mode in the horizontal wavelength range 50000 km > \lambda/2 > 170 km. Among the results, one finds that the motion of elements with small horizontal wavelength is limited to a thin layer near the top of the convection zone.


Observations of the solar corona made at the Crimean station of the Institute of Physics are summarized. It was found that the lower limit to the velocity of the plasma ejected from the sun during the period of maximum solar activity is 1 km/sec.


The variation of the equivalent widths of FeI and TiII toward the solar limb is studied by means of the curves of growth. The velocities of microturbulences in the range of optical depths 0.04-0.001 increase slightly toward the surface from 1.10 km/sec to 1.50 km/sec. It is also possible that there is a small anisotropy of the velocities.


Faculae, fiooculi, and certain types of coronal rays are closely associated with magnetic regions. These phenomena may result from acceleration of matter in the upper layer of the convective zone. A weak field will reduce turbulence in these regions, making the flow more stable. This decreases dissipation and increases convective velocity. The low field strength should determine the brightness and depth of the upper boundary of polar faculae. Heating from polar faculae should then give rise to the polar coronal rays.

Comparatively rapid amplitude variations of the received signal are sometimes detected when observing the radio emission of the Crab nebula during its occultation by the solar supercorona. This effect is explained by the screening of the radio source by a plasma cloud moving in the supercorona. The lower limit to the velocity of motion is \((2.5-15) \times 10^3\) km/sec.


It is shown that there should be enough energy available in the solar convection zone to heat the chromosphere by dissipation of weak shock waves even if the effect of scattering of solar radiation in the chromosphere is taken into account.


The propagation along the magnetic field of low-frequency electromagnetic, transverse viscous and longitudinal oscillations in a plasma is considered. The energy exchange between different forms of waves is considered. Qualitative applications to the solar corona follow, when appropriate.


Evidence is given that the active regions are the source of certain types of corpuscular radiation. Several arguments suggest that sunspots and quiescent filaments do not play an essential role here. The stability of the corpuscular streams is shown to be associated with the local magnetic fields of the active regions. The concept is advanced that each corpuscular stream is an assembly of stable, relatively dense tubes of force with frozen-in magnetic fields.


Some observations on the behavior of magnetic fields during flares are described. Analysis suggests that flares may be generated by contraction of solar plasma near a neutral point under the action of the increasing external magnetic field of a sunspot. It is also shown that ohmic losses can play an important role in the slow heating of faculae.


M-type corpuscular streams are analyzed by assuming that they are represented by solutions to the stationary equations of magnetohydrodynamics for an ideal compressible fluid of infinite electrical conductivity in a frame of reference rotating at constant angular velocity where the velocity and magnetic field vectors are parallel. The evolution of the flow paths in response to small steady-state disturbances is studied.

The total energy of high-energy particles estimated from IGY and IGYC data is found to be at least as high as the energy in all other forms liberated during solar flares.


Diffusion of gas from the bulk of the corona is computed due to currents set up by the electrostatic fields established, in turn, by different charges on unevenly heated coronal regions. Deviations of the velocity distribution of particles from a Maxwellian distribution are computed. It is shown that this deviation can reduce the flow of protons by one order of magnitude with significant effects on the coronal electric field and charge.


The enhancement of La radiation suggests that the flux of wave energy from the convection zone to the corona is about 5 times as high in active regions as in the quiet sun. This corresponds to an increase in the convective velocity of about 20%. The base of the corona is lower and more dense above the active regions.


This paper describes how convective motions occurring deep in the outer solar convection zone could redistribute the surface magnetic field lines so as to form a network covering the sun's surface. This network would then control motions associated with chromospheric spicules observed in CaII and Hα.


Recent observations of the contrast ratio of facular intensity over photospheric intensity in the continuum yield a facular model in which the excess radiative flux in the faculae arises from additional energy transfer due to increased convective motions in the active regions.


Type II radio bursts are thought to originate in plasma oscillations which can only be generated if the drift velocity of the electrons is greater than the thermal velocity. Since this condition is not fulfilled for a regular corpuscular stream, a mechanism is required to produce it. A collisionless shock wave provides such a mechanism. Estimates show that type II radio emission (with the observed order of intensity) can be obtained in this way.


The average velocity of rotation at the solar equator is derived from averaging 1700 lines of different elements with
different intensities. The value obtained is 2.06 km sec\(^{-1}\). The difference from one line to another, even in cases where the two lines come from the same element, is as high as ± 0.5 km sec\(^{-1}\). The velocity of solar rotation decreases as the optical depth of a particular line increases. Thus the measurements confirm the differential rotation of solar layers at different depths.


A system of spectral equations of magnetohydrodynamic turbulence which takes into account the suppression of small-scale motions by the large-scale magnetic field is proposed. Observational data on the turbulence in the solar photosphere are used to derive the system. The spectral functions of the magnetic and kinetic energies are inversely proportional to the square of the wave number in the small-scale region. The critical value of the superadiabatic gradient increases proportionally to the first power of the magnetic field.


It is shown that if the energy flux of acoustic waves just balances the energy carried off by radiation in a stellar chromosphere, the emission measures and electron densities for these chromospheres can be computed easily. On this basis, it is estimated that F5 giants and early supergiants should have the most powerful chromospheres. If active and undisturbed solar regions are considered as separate atmospheres, it is shown that a 30% increase in convection speed is required to account for the enhanced electron density in the active region.


The excitation mechanisms of types II and III radio bursts are discussed from the viewpoint of the velocities of their sources in the solar atmosphere. It is concluded that a hydrodynamic shock caused by an initial disturbance like a flare surge can excite type II radio bursts whereas the only possible agent from the velocity viewpoint which could cause type III bursts is the streaming of individual particles.


From an extensive analysis of the profile of the NaD\(_1\) line and its center-limb variation, the author concludes that, among other things, the turbulent velocity at the uppermost photospheric level is smaller than 2 km sec\(^{-1}\) where the Doppler core of the line is formed.


The acceleration of thermal electrons to relativistic velocities so they may produce type IV radio emission by the
synchrotron mechanism is thought to occur in two stages. First, they are accelerated by Alfvén waves in the lower corona permeated by sunspot magnetic fields. Then a redistribution of velocities occurs due to collisions with ambient thermal electrons. The accelerated electrons tend to collect in regions of high magnetic field strength over sunspot groups and some may be carried out when part of a sunspot field is carried out in ejected ionized gas clouds. These two potential sources of radio emission coincide with observed positions of radio sources at microwave frequencies and sources of meter-wave type IV bursts.


This paper is an extension of a previous effort by the author and W. Unno to develop a mathematical treatment of turbulent noise generation applicable to the outer solar convection zone. The atmosphere is convectively non-neutral and gravity effects are included. It is shown that the total power generated as acoustic noise depends on the nature of the turbulence, which in turn depends upon the degree of convective instability of the atmosphere.


The scattering of acoustic waves in a turbulent medium is studied under the assumption that the velocity field is small compared with the sound velocity. It is found that the effect of density stratification is to scatter the sound waves predominantly in a horizontal direction. The formula becomes equivalent to the one derived by Kraichnan if the scale height is infinite. Application is suggested to the penetration of sound waves generated inside the outer solar convection zone to the radiatively stable layer.


The shock wave heating of the solar corona is studied for cases with and without a magnetic field whose source is a magnetic dipole buried in the photosphere. The magnetohydrodynamic equations are solved for zero viscosity, infinite electrical conductivity, constant specific heat ratio and constant gravity. Shock dissipation, thermal conductivity and radiative flux are represented by approximate expressions, the latter in three different atmospheric regions. Surface boundary conditions are chosen from best current estimates. The solution gives the temperature, density, macroscopic velocity and conductive (thermal) flux as functions of height above the limb. Generally speaking, the magnetic field increases the values of these parameters at a given height, but not by a very large amount. In both cases, the solution yields a sharp temperature gradient in the region 1500–6000 km and large values for the conductive flux.

The statistical method of investigating turbulent convection suggested by Ledoux, Schwarzschild, and Spiegel (1960) is examined and developed. Closed equations are found for the spectra of the mean square velocity, the mean square temperature fluctuation and the mean convective heat flux. Solutions of these three equations are investigated with the outer solar convection zone in mind.


Turbulent velocities in the chromosphere were determined from the base up to 10000 km using data from flash spectrograms of the 1958 eclipse. The velocity was determined by the multiplet method. The velocity appears to vary from 2-3 km sec\(^{-1}\) to 17 km sec\(^{-1}\) as one ascends from 0 km up to 2000 km and then remains constant up to 10000 km. The random velocity within each spicule was estimated to be less than 7 km sec\(^{-1}\). Since these velocities are about three times larger than those deduced from an analysis of \(K_3\) reversal, a new model of the chromosphere is proposed consisting only of spicules which penetrate to the base, the \(K\) line observed then arising from two regions, chromospheric spicules in motion and photosphere-reversing layer at rest.


The large-scale motion at the solar photospheric level is examined as a collective motion due to influences of compressibility on the turbulence with low Mach number. Theoretical results for the horizontal scale of the turbulence are in reasonable agreement with observations.


A systematic difference is observed between dimensions of photospheric granules observed near the penumbra of sun spots and of those observed farther away. This difference is attributed to the influence of magnetic fields, though no detailed mechanism is proposed.


Spectroscopic observations of chromospheric spicules show that the material in the spicules rises into the corona, but does not descend during the time the spicules remain visible in \(H_\alpha\).

Relation between Motions and Local Magnetic Fields in the Photosphere; Bumba, V.; B. A. C., 14, 1, 1963.

The maps of the distribution of radial velocities and magnetic fields in sunspot groups show that strong local magnetic fields exert a determining influence on the organization of the motion,
provided one disregards the detailed structure, and that the photospheric plasma is largely frozen into the local fields. Measurements carried out with higher resolving power reveal a reversal in the direction of the radial motions in the Evershed effect at the periphery of the spots.


The chromosphere was photographed at various wavelengths across the Hα line. Photographs of velocity distributions are obtained using a process of photographic subtraction. At all depths, there is a close correlation between the intensity of the granules in Hα and the vertical velocity with the darker granules falling.


Various hydrodynamic models of the solar corona are briefly considered. The hydrodynamic equations yield both fast solutions in which the gas expands outward at supersonic speeds and slow solutions in which the expansion velocity vanishes asymptotically. It is pointed out that previous contentions that the slow solutions are unacceptable as they give a finite pressure at infinity may be incorrect. This could be the case if, as seems possible, the self-attraction of the expanding gas becomes significant asymptotically and thereby compresses the gas in transit to yield zero pressure at infinity. Arguments are given indicating that the pressure may be anisotropic in the local rest frame of the expanding corona. It is suggested that the observed solar wind may be a manifestation of this anisotropy.


This paper provides a critical discussion of the previous one, including a refutation of the contention that there is no basic objection to a corona which expands slowly or is static. The author points out, for example, that an infinite attractive mass is required if the conditions of self-gravitation required to obtain a zero pressure at infinity are met for a slowly expanding corona.


An effort is made to resolve the discrepancy which exists between coronal temperatures derived from line widths and electron temperatures compatible with the various ionized stages of coronal ions. To do this, calculations are made of the Doppler broadening of the coronal line 5303 Å for various temperatures assuming that Parker's model of a rapidly expanding, spherically symmetric corona is correct. It is shown that an appreciable contribution to the line width can arise from expansion if the temperature is high enough. Comparison of calculated line widths with measurements of A. H. Jarrett and H. von Klüber suggests a coronal temperature less than $1.5 \times 10^6$ °K, but greater than the $1.22 \times 10^6$ °K Parker found as sufficient for expansion.

The coronal temperature is calculated assuming that the flux of acoustic energy originating in the convection zone is responsible for coronal heating. Use is made of Vitense's model of the convection zone, Lighthill's theory of acoustic wave generation in a convective region and Schatzman's theory of the propagation and dissipation of shock waves, formed from the acoustic waves in the chromosphere. Account is taken of thermal conduction and radiative losses in the corona. The temperature calculated is $6.5 \times 10^5 \, ^\circ\text{K}$, lower than any observed value. However the present treatment neglects magnetic fields, inclusion of which should provide some increase in the temperature. Nevertheless, it is concluded that acoustic heating alone cannot supply sufficient energy to maintain coronal temperatures on the order of 1.5 to 2 times $10^6 \, ^\circ\text{K}$.


The longitudinal magnetic fields of single granules are less than 40-60 Gs. The groups of granules have fields 50-60 Gs coinciding with the places of largest radial velocities.


The balance between acoustical heating and radiation cooling is considered. The shock may be used for an explanation of regions with two different temperatures.

The Motion of $\text{Ca}^+$ in the Chromosphere and the Connection of the Motion with Magnetic Fields; V. E. Stepanov; Publ. Crim. Obs., 23, 184, 1960.

A large scale turbulence (5000-20000 km, 3.6 km/sec) is found. The velocity of ascending gas is 0.96 km/sec, descending gas 1.25 km/sec. The mass of downward flow in flocculi is more than three times larger than in upward flow. In the undisturbed chromosphere the balance is equal.


Characteristic Features of the Fine Structure of the Chromosphere in the $\lambda 3932$ Ca II Line; T. T. Tsap; Publ. Crim. Obs., 26, 45, 1961.

The life-times and motions of bright chromospheric knots outside the active region are studied.


Tangential motions in the chromospheric flocculi and motions at photospheric level are studied.


The theory of propagation and decay of shock waves in inhomogeneous media is used for determination of scale heights in the chromosphere.


An "unadiabatic" criterion of convection stability is studied.
SUNSPOTS


High-definition time sequences of sunspots were obtained in a continuation of Project Stratoscope. Their penumbra is resolved into a complex array of predominantly radial bright filaments. These filaments are long, narrow structures having widths of 300 km or less and lengths of the order of 5000 km. Their lifetime is roughly five times that of the granules.


Linearized equations derived by Chandrasekhar describing convection in the presence of a magnetic field have been used to derive growth rates of convection cells as a function of the magnetic number Q and the Rayleigh number R. These calculations are applied to the penumbra of sunspots assuming a uniform magnetic field of 1000 gauss and physical parameters appropriate to the outer layers of the convection zone. It is found that long, narrow convection cells result if the magnetic field in the penumbra is nearly horizontal, as suggested by the Evershed effect. These convection cells are shown to be consistent with the known properties of the penumbral filaments.


This investigation of sunspot velocity fields uses a line (FeI λ5576.101) for which the Landé splitting factor g = 0. Doppler displacements were measured at over 100 points in the region of both a large and a small sunspot. A comparison with predictions by Kinman for large and small spots is provided. The agreement is very good for the small spot, but much smaller radial velocities were observed for the large spot than Kinman predicted.


High dispersion spectra of 0.2Å/mm taken during the passage of one sunspot across the solar disk are used for simultaneous micrometer and photometric investigations of a sunspot velocity field. The spectral line FeI at λ5576Å was selected because it is unaffected by sunspot magnetic fields due to the zero valued Landé splitting factor. Solutions are attempted for both umbra and penumbral velocity components. The micrometer measurements show that the umbral motion is characterized by a small vertical velocity of descent of approximately 0.1 km sec⁻¹, while the predominately radial penumbral velocity field pattern appears to be both flattened and broadened during the passage of the spot from center to limb.


A preliminary investigation points to a close connection between the intensity of the sunspot umbra and the magnitude of the Evershed effect. On three occasions, rather large Doppler displacements were found. If the velocity is parallel to the solar surface, these velocities are comparable to the photospheric velocity of sound.

The velocity field is determined from measurements of a complex sunspot. Detailed observations of a single roundish spot during its transit across the disk permits the calculation of mean velocity components as a function of the distance from the spot center. The variation of the horizontal component is in accord with previous work, but there also appears a small vertical downward component not previously suspected. There is a treatment of line profile modification in the sunspot penumbra associated with the Evershed effect. The change is thought to result from the velocity gradient with depth in the line-forming layers. Finally, from a statistical study of the relations between the intensity of photospheric granulation, small scale Doppler shifts and fluctuations of equivalent width for a few lines, it is concluded that bright granules may indeed be associated with ascending motions while dark elements should be related to descending motions. However no quantitative relation between brightness and velocity emerged.


This paper is a study of velocity as a function of horizontal position in sunspots. The velocity is found to increase monotonically with increasing horizontal distance from spot center. At the outer limits of the penumbra, however, the velocity falls abruptly to zero.


About one hour after the onset of four different solar flares, series of dark loops emerged between different parts of each flare. These loops expanded by several km/sec, achieving a maximum diameter of about 60,000 km. Downward motions of material were observed at both ends of the dark loops with velocities of about 100 km/sec. These downward motions apparently followed field lines, while the loops bridged zero lines of the longitudinal magnetic field. The observed lifetimes of several hours indicate that the descending matter is continuously replenished by condensed coronal matter.


The observed movements of sunspots seem to indicate that the immediate cause of sunspots is to be found in vortices produced by the differential rotation of the sun. It is shown how these sunspots so formed amplify the local magnetic field through their motions.


High-definition photographs from Stratoscope I were surveyed to study granules in the vicinity of sunspots and the motions in sunspots. It was found that granules tend to have smaller mean diameters, longer lifetimes and a somewhat different structure when found near sunspots. Bright knots seen in the penumbral filaments...
show systematic motion away from the center of the spot with velocities around 1-2 km sec$^{-1}$. These motions representing the Evershed effects are interpreted as an almost horizontal convective streaming along magnetic lines of force.


Growth curves based on the VI and the FeI lines were plotted for the larger sunspot of July 14, 1953. The measured Doppler velocity of 1.75 km/sec was larger than the corresponding value for the thermal velocity. This increase in velocity is apparently due to fine scale turbulence, since no correlation between increased equivalent line widths and splitting of lines in the magnetic field was evinced.


It is shown that the velocity fields describing the motions of nonrecurrent sunspots in latitude in different years comprises a single aggregate.


Arguments are given to show that the magnetic fields of sunspots represent a local intensification of the general solar magnetic field. It is suggested that the field of a bipolar spot group is generated by large-scale convective mass motions in the subphotospheric layers. A system of toroidal fields lying in vertical planes parallel to the solar field and containing the convective elements is formed. These fields combine to form the field of a bipolar spot group upon emerging at the solar surface. Their structure agrees with observations which strongly suggest that the field of each spot has two polarities.


The physical states in several sunspots were studied from spectroscopic data and a model was developed which gives reasonable agreement with temperature and electron density distribution, at least in the case of the penumbra. Among other conclusions is one that there is a significant departure from hydrostatic equilibrium in the penumbra, but that this can be explained by a reasonable magnetic field which lies parallel to the Evershed flow. Also, it is found that the model sunspot blends into the surrounding photosphere by the Evershed flow.

Contribution to the Discussion of Radial Motions in Sunspots; Bumba, V.; B.A.C., 14, 137, 1963.

High resolution photographic and photoelectric measurements of the Evershed effect are discussed. A modified working model of the motions in a regular spot is described. It appears that the Evershed motions are not the only type of radial motions in spot groups. It is concluded that the model of the regular spot is not adequate to handle the theoretical problem of time evolution and cooling of a sunspot.
The Evershed velocities have been studied from H filtergrams. Inward motions are found to extend from the outer boundary of the penumbra to two sunspot radii. The moving matter is not evenly distributed around the spot but flows in long channels. These have lifetimes of about 9 hr., which is very long compared to the time of passage at inflow velocities of 45 km sec⁻¹. The velocity vector appears to make an angle of 13° with the solar surface, suggesting that the matter is constrained to flow along lines of magnetic force. If so, the high inflow velocities may be purely gravitational.

Biermann’s suggestion that sunspots owe their darkness to the inhibition of the convective energy transport due to magnetic breaking of upward convective motions is discussed. It is noted that, in a vertical magnetic field, upward motions along the lines of force are not inhibited but that the associated smaller scale turbulence which leads to dissipation of the convective energy flow by viscosity cannot occur. It is concluded that this is the mechanism inhibiting convective energy transport.

The asymmetry due to the Evershed effect is found.

The strengths and configurations of the magnetic field of single sunspots were studied photographically and photoelectrically. The secondary polarities are found. The gradient with height is also obtained.

The asymmetry of the line profile due to the Evershed effect and "flag" phenomena are found.

The comparison of general theoretical discussions based on hydro-magnetism with observational results found by the author.

The investigation of the Evershed effect.


On Linear Velocity of Proper Motion of Solar Spots; Shpichka, J.V.; Circ. Lvov Obs., No. 37-38, 17, 1962.
PROMINENCES AND FLARES

Prominence Characteristics in Regions of Bright Coronal Emission;
Prominences showing a high degree of fragmentation and large internal motions are found to be most prevalent in regions of high coronal density. The authors conclude that prominences which carry matter in greatest quantities from the corona to the solar surface are located within regions of high coronal density. The fading and reappearance of prominence matter suggests a continuous interchange of matter between the hot ambient coronal gas and the cooler prominence material.

A new class of optical phenomena of the solar atmosphere associated with flares has been observed in H images of the solar disk. These phenomena are characterized by higher velocities (500-1500 km/sec) and shorter time scales (few seconds—a minute) than have been indicated by previous observations. An explanation of some of the observed phenomena is offered in terms of corpuscular streams ejected from flares during an explosive phase occurring during the rise to maximum brightness.

The continuum and line emission of a limb flare of March 7, 1959, are discussed. An analysis of the continuum emission near the Balmer limit shows that the kinetic temperature of the flare must be considerably less than 20,000 °K in that region where the hydrogen is excited. A model is derived for the temperature, electron density, and gas pressure as a function of distance from the axis, assuming the hydrogen emission to be axially symmetric. The temperatures so derived are much lower than those obtained from the usual methods of line-width analysis, which, it is suggested, are of questionable value when applied to active limb events.

A detailed photometric study is presented of the line and continuous spectrum of the limb flare of June 9, 1959. The electron temperature is found to be certainly less than 24,000 °K in the bright, dense central portion of the flare, where the hydrogen lines and continuum are excited. The flare occurred as a condensation in an active coronal region, yet the temperature is only slightly higher than that observed in a spray-type flare that originated at the chromospheric level. The authors tentatively suggest temperatures of 10000 °K and 20000 °K, respectively, for "cool" and "hot" prominence classes suggested by Zirin and Tandberg-Hanssen.
A study of the frequency distribution of heights of nearly 50000 prominences observed on K-spectroheliohograms during a complete solar cycle shows a nearly exponential decrease in frequency with increased height between 20" and 220" of height above the chromosphere.

Coronal temperatures of $4 \times 10^6$°K which are reported following a large solar flare are shown to be capable of producing a hydrodynamic blast wave, moving out through interplanetary space with velocities of 1500 km/sec and densities from a few times $10^2$ cm$^{-3}$ to $10^3$cm$^{-3}$ at the earth's orbit. The analysis follows classical hydrodynamic lines. The author contends that this hydrodynamic "explosion" of the enhanced corona may be the accelerating mechanism for the enhanced solar corpuscular emission which, in turn, induces the geomagnetic storms and low latitude aurorae observed at earth a day or two following large solar flares. He also shows how the outward sweeping magnetic shear in the blast wave will decrease the cosmic ray intensity in a manner very like the observed Forbush decrease.

This article gives, among other things, values for the macroscopic velocity of the flare and a brief discussion of the model which appears to represent it successfully.

The author discusses critically the three possible mechanisms known to date for converting magnetic energy into gas dynamic energy in an effort to solicit the energy source for solar flares. These mechanisms are (1) Joule dissipation, (2) ambipolar diffusion and (3) Sweet's mechanism. After noting that there would probably be enough magnetic energy available in the vicinity of a large flare, he concludes that this energy could not be liberated rapidly enough ($\sim 10^2$ sec) by any of the known mechanisms to support the flare. Thus, the problem of flare generation appears to be still very much open with need for either a new energy source or a new rapid mechanism for annihilation of magnetic fields.

A study of five solar events observed on a single day led the authors to conclude that either the general shape of the magnetic field above an active region is unaltered by flare events or that the magnetic field was restored to its pre-flare configuration in the course of the 2 to 3 hours between the events.

It is suggested that the mechanism responsible for converting magnetic energy into solar flare kinetic energy may reside deep in the photosphere below optical depth unity in the continuum. This mechanism would originate in the motions of high energy particles. It is even suggested that such high energy particles generated below the photosphere may be the energy source of solar flares.


The paper reports detailed observations of a type of lateral motion detected in an average of four solar flares of importance 2 or greater observed over a two year period. In all, 14 such motions were observed. These displacements of flare filaments occur as a pair of parallel filaments move apart in the neighborhood of sunspots with strong magnetic fields with lateral velocities up to 10 km sec\(^{-1}\).


Two major problems in the interpretation of solar flares are discussed: by what means can high concentrations of energy be stored in the chromosphere and what process will permit a sudden release of this energy during a flare? It is shown that the energy storage can be accounted for by a class of magnetic fields whose lines of force have the general shape of twisted loops protruding above the photosphere. A sudden release of energy in such a system can result only in a case where the magnetic forces drive the system away from its usual force-free configuration. This can occur when twisted magnetic loops of opposite sense and opposite twist meet, annihilating the longitudinal components of the field and leading to a rapid constriction of the chromospheric plasma with attendant energy dissipation.


The authors discuss the possibility that calcium ions, spiralling along the lines of force of magnetic fields within the observed prominence and thus experiencing a form of turbulent motion, can yield CaII H and K lines of the great width observed.


The solar flares of November 10 and 12, 1960, were photographed under excellent viewing conditions. The results are analyzed and light curves plotted in this report. Of particular interest is a phenomenon described by the authors as a flare nimbus found in association with some Class 3 and 3+ flares. This is a dark absorbing halo which begins to surround the flare some few minutes after the filaments have reached their maximum light intensity. The time of commencement, time of maximum visibility and dimensions are closely comparable with those of Type IV continuum radio emission. It is suggested that flare nimbi are the indirect effect of relativistic electrons moving in the flare.

Six maps of the longitudinal magnetic field were obtained for a small sunspot group on April 23-24, 1960. During the course of a I+ flare, a rather serious event for a small sunspot group, no change in the magnetic field could be detected. It was concluded that if important magnetic variations were associated with the flare, they occurred before the beginning of Hα emission.


An investigation is reported of the problem of cooling a coronal gas in a magnetic field under compression perpendicular to the field lines. The gas is adiabatically heated through the compression and loses energy by conduction of heat along the field lines and by radiation. The time required for the gas to cool to the temperature of a prominence is calculated and found to be sufficiently short.


The trajectories, velocities and accelerations of a large ascending filament have been measured. The filament ascended out of a region where neither spots nor faculae were observed. The velocities of the nearly radial motions were around 477 km/sec, and the accelerations up to more than three times the gravitational acceleration. The filament is considered as a magnetic bar and its ascending as a breaking which occurs when the magnetic pressure exceeds a critical value.


A detailed description of the motions in this large filament is provided.


Six flares, including three very large ones, which appeared in June and July of 1959 are studied in relation to their attendant sunspot groups. It was found that the large flares appeared during periods of continuously proceeding, important changes in spot and magnetic field structure, that in spite of changes in spot structure all flares originated at the same position relative to spot umbrae and that most flares originated in regions of strong magnetic fields, but never in neutral points of zero field strength.


A careful study of the motion of a large prominence of March 18, 1961, suggests that the prominence is carried away from the sun by the solar wind. The trajectory was observed out to 733,000 km and the velocity was found to increase outward, though the acceleration was decreasing. The material in the prominence appeared to obey the continuity relation, \( r^2 \cdot \rho \cdot v = \text{constant} \), and a limiting velocity for the prominence material was estimated as 500 km/sec. The long coronal rays are interpreted as stationary streaming of material which eventually merges with the steady-state wind.

Results of observations of two intense chromospheric flares show a similarity in structure which gives evidence of eddy or pseudoeddy motions and of a systematic movement of the principal emission knot in a western direction.


A pinch effect can be set up around the neutral point in a free magnetic field by rapid changes in a sunspot field if this field is external and of a dipole character. Strong shock waves converging at the neutral point can appear. As a result of reflection in the neutral plane, a high-temperature region is formed behind the reflected shock front which is moving to meet the contracting plasma. This region is heated by the magnetic energy expended in creating and compressing the shock waves. Thermonuclear reactions occur in this region.


The results of spectrophotometry of the limb flare are presented. Profiles are obtained for the Balmer lines from Hα to H9. It is shown that the Balmer-line broadening is due to macroscopic mass motions.


The author refines earlier models of a solar flare based on the pinch effect by showing how such a nonequilibrium situation might arise. He advances a possible mechanism for formation of the soft component of solar rays observed in conjunction with a flare and prior to the Forbush decrease.


Recordings of the magnetic field in active regions taken with a magnetograph and photographs of the sun show that the "humps" of both the field and the sunspots move during a flare. The magnitude of the displacement varies from case to case, often reaching 20000 km. The motions are generally toward flare nodes. The energy liberated by a flare is estimated, assuming that the observed displacement toward flare nodes is associated with a contraction resulting from a conversion of magnetic energy into thermal energy of the flare. The available energy is computed to be the order of $10^{32}$ ergs.


The kinetic energy of a typical class +1 limb flare is estimated as about $5 \times 10^{26}$ ergs from the theory of a strong, practically instantaneous explosion with cylindrical symmetry. The energy emitted in the flare in Hα, Lα, HeII λ304Å and also in the x-ray and continuous spectrum is estimated. The magnitude of all these forms of energy is of the order of $10^{28}$ ergs. It is concluded that if the flare results
from a strong explosion, its kinetic energy is insufficient to compensate the energy lost by the flare as all forms of radiation. Therefore, the total energy liberated by a strong explosion should be considerably higher than the kinetic energy of shock waves.


It is proposed that large chromospheric flares, followed by type III absorption in the earth's ionosphere at high latitudes, serve as the mechanism of escape for high energy particles generated and stored in eruptive active regions on the sun.


Two limb flares are investigated in detail. Among the conclusions is that high turbulent velocities existed in these flares ranging from 12 km sec\(^{-1}\) for the NaI line to 20 km sec\(^{-1}\) for HeI.


This analysis of a shock wave propagating into the corona or the transition region between the chromosphere and corona suggests that a region could be formed of lower temperature and higher density than the surroundings as a result of the increased radiative loss associated with compression. It is shown that one can obtain some characteristic features of spicules if we take for the material velocity behind the shock the observed velocity of the spicules, using the extended Rankine-Hugoniot relations for the shock by including terms for radiation loss in optically thin media. Observed features of solar-flare surges can be obtained from similar considerations.


A mechanism for formation of coronal prominences is proposed which allows the prominences to form by condensation of the coronal plasma rather than by ejection of material from below. Since the energy density of the solar cosmic ray stream is believed to be at least as great as that of the coronal magnetic field, a strong interaction should occur in which the cosmic ray stream expels the magnetized (magnetic field frozen in) plasma from a tubular region which is filled in turn by non-magnetized plasma from, perhaps, the inlet opened at a neutral point of a sunspot magnetic field. When the cosmic ray activity subsides, it is shown that the subsequent compression and radiative cooling of the gas column will lead to a final state which conforms closely to the observed state of prominences.


Included in this discussion of a flare surge are radial velocities inferred from observations of the H and K lines of CaII and the red wing of H\(_\alpha\).

The local brightness fluctuations in the solar photosphere are obtained from the centers of Fraunhofer lines of average and strong intensity. It is shown that these results are incompatible with some current models of the inhomogeneous photosphere consisting of hot rising and cold descending turbulent elements.

Motion Effects in Chromospheric Flares; Valniček, B.; B. A. C., 12, 237, 1961.

In flares whose shape undergoes changes, these changes are shown to proceed at velocities of three different ranges depending on the character of the changes: up to 10 km sec\(^{-1}\), up to 100-150 km sec\(^{-1}\), and up to about 1000 km sec\(^{-1}\). If not impeded by a strong magnetic field, the flares develop primarily in a plane. The magnetic field producing conditions favorable for a flare to occur may not be capable of confining the flare. A discussion of the types of flare motions and the mechanisms involved is included.

On a Peculiar Flare Spectrum; Švestka, Z.; B.A.C., 13, 30, 1962.

A peculiar flare spectrum characterized by a weak emission imbedded in an absorption is described and discussed. It is suggested that this originated in an approximately-spherical rotating ball with an emission core and an absorbing shell moving downward through the chromosphere at a height of several thousand kilometers at a velocity of about 18 km sec\(^{-1}\). Spectral lines are broadened, suggesting a microturbulent velocity of \(\sim 90\) km sec\(^{-1}\) in the region of the motion.


The H\(_\alpha\) striation pattern in the immediate vicinity of the active region of very large flares is seen to be obscured at times near flare maximum. This effect is discussed and, after considering and rejecting the possibility that partial destruction of the chromospheric magnetic field by the flare is responsible, the authors conclude that the observation is probably due to the opacity of material ejected from the flare.

The prominence observed May 19, 1956.

The temperature of excitation of He\(_\alpha\) is inferred.


The lifetime of bright knots of fine structure of flocculi is given and the relative velocity is about 100 m/sec.


An Investigation of Chromospheric Flares at the Initial Stages of their Development; Gopassjuk, S. I.; Publ. Crim. Obs., 23, 331, 1960. The application of the theory of the explosion with cylindrical symmetry. The heat energy is $10^{27} - 10^{28}$ ergs, the temperature in the center is $5.6 \times 10^6$ K.


Dynamics of Limb Flares and the Pinch Effect; Severny, A. B., Schaposchnikova, E. F.; Publ. Crim. Obs., 24, 235, 1960. It is found that the flares on the limb have the appearance of a changing brilliant hill, the upper front of which undergoes a rapid expansion and then contraction with velocities 50 - 600 km/sec and accelerations of $3.10^4 - 10^6$ cm/sec$^2$. These are the cumulative effects. The energy can be supplied by the annihilation of magnetic field 100 Gs in this region.


discussed. Strong shocks converge at the neutral point and heat the gas. Deuterium thermonuclear reactions can be produced during the flare.

The Influence of a Magnetic Field on Motions in Chromospheric Flares; Gopasyuk, S. I.; Publ. Crim. Obs., 25, 114, 1961. Observations of 1957-59 years are used for the comparison of motions and brightness in flares with respect to the photospheric field.

A Study of Emission Broadening in Strong Lines of Flares and Moustaches; Severny, A. B., Koval, A. N.; Publ. Crim. Obs., 26, 3, 1961. The broadening is the result of fast (∼ 300 km/sec) jets formed during the contraction or elongation of the flare.


Metallic Line Emission in Flares; Stepanyan, N. N.; Publ. Crim. Obs., 29, 68, 1963. The development of flares in different lines is interpreted by the propagation of a shock wave from the region of its origin.


The Location of Great Flares in Magnetic Fields of Spot Groups; Severny, A. B.; Publ. Crim. Obs., 30, 161, 1963. The filaments of flares tend to be located along the lines, joining poles of the same sense and containing the neutral point,
or along (or parallel to) the neutral line of the longitudinal field. The flare filaments always pass through the neutral point of the transversal field. Neutral points can appear inside umbrae and above the strong transversal field.

Absorption surges' appearances are connected with the formation of flares and their knots or with the new increasing of their brightness. These surges are ejected from spots during the whole lifetime of a flare, and move along the magnetic field.

The velocity, determined from the half-widths of the line profiles, is about 30 km/sec.

Data on fields immediately before, during and after a flare 22.VI.1962 again point to the complication and increasing of the field before the flare and the simplification and weakening of the field after it.
A Suggested Mechanism for the Ejection of Matter from M-Type Stars;
It is suggested that matter is ejected from M-type stars by the
outward force due to a strong chromospheric Lyman-α radiation from below.

Molecules and Late Type Stellar Models; Vardya, M. S., Wildt, R.; Ap. J.
131, 448, 1960.
A difficulty encountered by Osterbrock, when he tried to identify
particular red dwarf stars by interpolating between his models of late-
type main-sequence stars, is shown to be alleviated by including the
effects produced by hydrogen molecules in the convective zone. This
derivation replaces the superadiabatic gradient by a more general
adiabatic gradient in hydrogen-helium mixtures obtained from thermo-
dynamics. Account is taken of the interlocking ionization of hydrogen
and helium and of its coupling with the association of hydrogen into
molecules. The effect is to extend the convective zone farther out
in the atmosphere.

Observational Limitations to Mass Loss by Normal Late-Type Giants;
Spectroscopic observations of H and K lines of Ca II in several
hundred late type stars are discussed, and it is shown that the
measured displacements provide no evidence for ejection of matter from
normal giants earlier than M0. Also, simple calculations show that the
absence of true circumstellar lines from the spectra of these objects
implies a rate of mass loss less than 10⁻¹⁰ solar masses per year.
Hence, if these stars must lose a substantial portion of their masses
before becoming white dwarfs there appear to be only two alternatives:
either they all must eventually evolve to M-type stars and remain such
long enough to eject the necessary amount of matter, or they are ejecting
matter at present by some unknown mechanism which permits the process
to escape observation.

The Motion of Gas Streams in Closed Binary Systems; Prendergast, K. H.;
An approximate solution of the equations of hydrodynamics is ob-
tained for the flow of gas in the vicinity of a closed binary system,
assuming that the pressure terms in the equations are small compared
with the gravitational, centrifugal, and Coriolis forces. An elemen-
tary solution of the equation of continuity is obtained. It is as-
sumed that hydrostatic support prevails in the direction normal to the
orbital plane. It is shown that the gaseous envelope is thin unless
the mean-square turbulent velocity is comparable to the orbital velocity
of the stars. The flow pattern has been computed for the case μ = 0.25
and exhibits several features in common with empirical models con-
structed from observations.

Coronal Evaporation as a Possible Mechanism for Mass Loss in Red Giants;
The consequences of the possible existence of a corona of a red
giant are investigated from a hydrodynamic point of view, under the
assumption that deposition of mechanical energy is confined to a narrow layer just above the surface of the star. Because of the energy loss due to radiation, it is shown that subsonic flows do not exist and that hydrostatic solutions exist only under special circumstances. In contrast, steady supersonic flows are possible with a significant attendant mass loss from an evolutionary point of view. However, these flows apparently must be ruled out as observed lines are not displaced sufficiently to conform to theoretical predictions with supersonic flow.


Using a simple model for the dissipation of energy by shock waves, the structure of the chromospheres of stars with different values of surface gravity is discussed. Sharp jumps in temperature at certain critical points would be expected. From this model, one gets reasonable chromospheric structures for white dwarfs, but not for stars of very low surface gravity unless very long period shock waves are considered. The thermal stability of these solutions is discussed.

The Convective Instability of a Radiating Fluid Layer; Spiegel, E. A.

The thermal stability of a gray, radiating fluid layer with an adverse temperature gradient is studied. The vertical dimension of the layer is assumed much less than the pressure or density scale height. By essentially dimensional reasoning with the same equations from Rayleigh's classical study which ignored the radiative term, it is shown that convection can occur when a non-dimensional parameter analogous to the Rayleigh number exceeds a critical value. Direct application is restricted to early type stars. The convective stability of the atmosphere of a BO star is discussed in terms of the results.


A general formula for deriving the broadening function as a result of the difference in line-of-sight motion of absorbing or emitting media at different parts of a stellar disk is derived by use of the so-called "isoradial velocity-curves." The formula is applied to the study of differential rotation of a single, as well as an eclipsed, star.


A procedure is described by which, under certain assumptions, the turbulence spectrum can be derived for the motions in a convectively unstable layer. The procedure is carried through for an exceptionally simple case for which a closed solution was found for the spectrum. The results are applied to convection in the solar photosphere for orientation, though they are not strictly applicable there.


Recent photoelastic observations of YZ Canis Minoris show the flare phenomena of dMe stars to be quite complex. Deviations from the usual exponential fading from maximum brightness cannot be explained by simple radiation cooling of a heated area.

From observations of the solar wind and of the M giant α Herculis the gross dynamical features of the stellar-wind regions associated with class G main-sequence and M giant stars are predicted, subject to the assumption that the mean-free paths of the individual atoms and ions of the stellar wind are small compared with the scale of the flow so that the conventional hydrodynamic equations are applicable. Unless current density estimates are wrong by more than a factor of 10, this assumption is valid. It is shown that stellar winds should extend to approximately that distance at which the dynamical pressure of the stellar wind equals the stagnation pressure of the interstellar medium and that the supersonic wind from a class G star should undergo a shock transition at this distance which proves to be from 10^{-5} a.u.
The wind from a M giant may be expected to extend many parsecs if the M giant phase lasts as long as 10^5 years.


Rho Cas appears to be surrounded by a shell which is expanding at ~ 40 km/sec relative to the photosphere. Conditions within the shell, analyzed over the period 1955-1960, are shown to change abruptly over one approximately two year period with the initial values restored at the end of the two years. Values of neutral hydrogen density, electron density, excitation temperature and ionization temperature are derived for the shell using a curve-of-growth analysis. Further study of radiation from this star, revealing a pronounced weakness in the Balmer absorption lines, suggests a hot chromosphere between the photosphere and the relatively cool shell. It is suggested that a mechanical energy source is required to heat the chromosphere, perhaps a flux of turbulent energy from the photosphere for which there is some evidence. Finally it is noteworthy that Rho Cas appears to be losing mass at the rate of 10^{-5} stellar masses per year.


Theoretical calculations which yield the constant permitting one to join core solutions to atmospheric solutions for stars with convective envelopes are used to estimate the depth of these envelopes. The convection zone of the sun is found to extend to 30 per cent of the solar radius in reasonable agreement with current estimates.


Consideration of basic energy and momentum conservation requirements together with observations of circumstellar lines in α Ori suggest an extensive hot region surrounding the star, if purely hydrodynamical mechanisms are to explain the mass ejection. If the observations are interpreted as representing a single shell of mass moving under gravity, rather than a continuous outflow, the absence of any observable change in the velocity or strength of the lines would require the matter to be at such a distance from the star that the envelope would be resolvable from the star.

The relation of the hydrogen ionization zone to stellar pulsation is discussed. A detailed analysis of this zone in SU Draconis shows it to be an important energy source for driving pulsations. An examination of conditions in other RR Lyrae stars, cepheids and W. Virginis stars suggests that the hydrogen ionization zone is important in determining the phase lags and in driving their oscillations. It is proposed that non-spherical, pulsation-type motions are present in all late-type giants and supergiants and provide the principal means of energy transport in the hydrogen ionization zones of these stars. It is shown also that the dissociative transition of molecular hydrogen may provide the heat sink necessary to explain the behavior of the class of cool variables which includes the Mira and semiregular red variables.


A curve of growth analysis of the circumstellar lines in α Ori based on high dispersion spectrograms is used to infer the physical conditions in the circumstellar envelope. The ejection rate is estimated to be $4 \times 10^{-6} M_\odot$ yr$^{-1}$. Except for the H and K lines of Ca II, the radial velocities of all the neutral and ionized lines are identical. No detectable systematic change in the strength or velocity of the circumstellar lines has occurred in the last twenty years.


An explanation is offered for the occurrence of the nearly equal frequencies and associated beats in the light—and in the velocity—variations of the B Canis Majoris stars. It is shown that if a star with specific heats ratio 1.6 is rotating, any disturbance will excite two normal modes with nearly equal frequencies.


From the widths of weak, unblended lines in the spectrum of ε Vir the authors conclude there exists either a macroturbulence of $3.6 \pm 1$ km/sec or a rotation where $V \sin i = 4.8 \pm 1.3$ km/sec. A microturbulence of from 2 to 3 km/sec is derived from the curves of growth.


The rotation of a viscous shell is analyzed where the viscosity is caused by convection and is not isotropic. The problem can be solved approximately for sufficiently high viscosity (or sufficiently slow rotation), using a physically plausible assumption for the viscosity tensor. The solution shows meridional circulation and differential rotation in the shell. Numerical solutions for constant density and viscosity in the shell are found and compared with motions in the hydrogen convection zone of the sun inferred from observations of granules.

As a step toward understanding the spectra associated with shock waves in a stellar atmosphere, an investigation is conducted to determine variations in temperature, mass density and electron concentration in a plane steady shock in pure hydrogen where the effects of viscosity, thermal conductivity and electric and magnetic fields are neglected but where the effect of Lyman continuum radiation from the hot region behind the shock on the preshocked gas is considered. Under the further assumptions that cooling occurs through radiative recombination alone and that the hot region is optically thin to the continuum but thick to all lines, it is shown that the inclusion of precursor radiation effects significantly raises the gas temperature behind the shock and that recombination of electron-ion pairs formed ahead of the shock by precursor radiation cannot occur ahead of shock. Results agree well with observations in predicting intense, broad Balmer lines and a weak Balmer continuum in variable stars.


A method for removing the implicit assumption of small mixing-length from current theories for turbulent convection in stars is described. It is indicated how the resulting equation may be used to include the effects of penetration into convectively stable regions as, for example, in the "overshoot" problem of the solar atmosphere.


Three modes of mass ejection from one or both components of a binary system have been idealized in an effort to predict their effect on the orbital period of the system. The modes of mass loss studied are usually referred to as Jean's mode, the slow mode and the intermediate mode. Application of results to Beta Lyrae is attempted.


The effect of angular momentum transfer between the binary system and the ejected mass from one or both components of the system is studied.


The hydrodynamic momentum and mass flow equations are integrated for a spherically symmetric stellar corona, assuming the temperature is a known function of radius. The general properties of the equations are discussed, and it is shown that if the thermal velocity is small compared to the gravitational escape velocity
and if $T(r)$ declines outward more slowly than $1/r$, the corona is quasi-static at its base and expands to supersonic velocity in space. The stellar mass loss resulting from the expansion can be determined from the coronal temperature distribution between the base of the corona and the point at which the flow becomes supersonic. This paper is the first in a series wherein the author attempts to extend his generally successful hydrodynamic theory of the expanding solar corona to other stars.

**Dynamical Properties of Stellar Coronas and Stellar Winds. II. Integration of the Heat Flow Equation; Parker, E. N.; Ap. J., 139, 93, 1964.**

The restriction of assuming a $T(r)$ in the first paper of this series is removed by introducing the heat flow equation which is solved for $T(r)$ under the condition that energy is supplied outward from the base of the corona by thermal conduction alone. The motivation is partially academic and the author is careful to point out that he does not consider this the only possible mode of coronal heating. The equation is solved analytically under a variety of circumstances: high, intermediate, and low coronal density and high temperature which may correspond to some giant stars with low gravitational escape velocities, solar type stars, certain white dwarfs and some very active stars, respectively. It is shown that the energy flow to infinity is non-vanishing for finite coronal density and thermal conductivity, that the temperature declines less rapidly than $1/r$, and that a supersonic stellar wind is an inescapable corollary of assuming negligible pressure at infinity.


The propagation of both weak and strong shock waves in adiabatic and isothermal atmospheres is treated in some detail, with expressions given for the rate of change of shock strength with distance in plane, cylindrical, and spherical atmospheres. Applications to the solar atmosphere are considered.

**Dynamical Properties of Stellar Coronas and Stellar Winds. III. The Dynamics of Coronal Streamers; Parker, E. N.; Ap. J., 139, 690, 1964.**

This investigation demonstrates that the mean values of the solar wind velocity and density at large distances from the sun are not affected to any great extent by assuming that all coronal material is confined to the observed streamers or filaments. This conclusion remains true even if the streamers occupy a very small fraction of the coronal volume near the base, although it is shown that at large radial distances the streamers must occupy most of the space available. It is concluded that the Helmholtz instability may disorder and mix the streamer and interstreamer regions beyond some radial distance on the order of 1 a.u. and that such mixing could explain some of the disorder observed by Mariner.
Small differential displacements of various absorption lines in the spectra of O Ceti and α Herculis lead the author to conclude that both stars are surrounded by an expanding gaseous envelope.

From studies of several spectral lines, it is concluded that the gaseous shell surrounding ζ Tauri was in an expansion phase during 1958-59 with the velocity of expansion increasing during these two years. Radial velocities are inferred from the data.

Spectroscopic evidence is provided to support the authors' view of a system of internal macroscopic motions which contrasts to a previous interpretation of data from IC 4997 which held that the entire nebula was rotating rapidly.

A section of this paper discusses how rotational instability causes the star to shed a disk of material which is probably magnetically coupled to the star. The instability of the disk is related to the winding of the magnetic field arising through the rotation. The process of disk formation and disruption can be repeated many times. The disruption time is computed to be of the order of 100 years.

The equation is set up which governs a small perturbation in a rotating stellar atmosphere with gravity and an axially symmetric magnetic field. A sufficient condition for stability is obtained.

The equation of hydrostatic equilibrium is reduced to a form suitable for calculation in the axially symmetric case, with full account taken of gas pressure, magnetic pressure and gravity. The nature of the solution is discussed and a simple example worked out in detail.

The equation of hydrostatic equilibrium of Paper II is reduced for the axially symmetric case in a more general manner. The method
is extended to the case where the star is rotating, under more restrictive assumptions on the atmospheric structure.


A rotating star has initially a purely poloidal magnetic field. However, in the presence of meridional circulation of matter, the convection of angular momentum causes a strong variation of angular velocity along a magnetic line of force and generates a toroidal magnetic field. This paper considers the possible steady states which may result. In particular, it is shown that if the circulation speed is less than the local Alfvén speed (defined by the poloidal field), the flow along a field line parallel to the surface will cause a steady increase of angular velocity towards the equator.

Turbulence and Rotation in Early Type Stars; Meadows, A. J.; *M. N.*, 123, 81, 1961.

The spectra of 54 early type stars are analyzed to discover the regions on the H–R diagram where turbulence and rotation are, respectively, the major sources of spectral line broadening. A demarcation between these two regions, which varies with absolute magnitude and spectral type, has been sketched out.


Calculations are presented to determine what types of stellar rotation and magnetic fields are unaffected by the meridional circulation fields which they are known to generate. A circulation fast enough to be of interest tends to distort the perturbation field driving it under most conditions. Two cases are treated: one with the centrifugal force the dominant perturbation, the other with the toroidal component of the magnetic field dominant.


Relative intensities of several red and green lines of OI are obtained for eight types of diluted atmospheres expanding at a uniform rate. The size of the expanding atmosphere can be deduced from relative intensities of red and green lines or from the red lines only.


The theory of shock wave propagation given by Brinkley and Kirkwood in 1947 has been extended to include the interaction of the material gas with a radiation field, as will be encountered in shock propagation in stellar atmospheres. The radial velocity of the variable 8-Cephei star, BN Vulpeculae, has been computed from the decay of shock waves in the atmosphere, using the newly developed theory. Good agreement is obtained with the observed radial velocity curve.

It is shown that a recent investigation of the radiative cooling behind a shock front in a stellar atmosphere is incorrect in its expression for the effective optical thickness of the shock front neglecting reabsorption of the shock radiation. The necessary correction is made and an alternative formulation provided.


The Brinkley-Kirkwood theory of shock wave dissipation is adapted to astrophysics by including the energy losses due to radiation. It is assumed that the matter cools behind the shock front until it has obtained the same entropy as before the shock, and then expands adiabatically to the same density and temperature. The equations obtained in this way are integrated numerically for parameters corresponding to the Beta Cephei star BW Vulpeculae. The computed curve is found to be in good agreement with the observed one.


Convective energy transport in a three-layer model atmosphere is investigated for the case where the two lower layers are convectively unstable, with a large departure from the adiabatic gradient in the actual temperature gradient in the upper convective layer, and the third, outer layer is in radiative equilibrium. The relation between the horizontal wave number of a disturbance and the degree of instability is derived for four different models. Among the conclusions, it is found that the rapidity of increase of instability with increasing wave number depends critically upon the presence and thickness of a radiatively stable layer above the convection zone with such a layer markedly increasing the stability of smaller convective elements. Also, it is noted that the assumption that the characteristic height of the mass flow is proportional to the scale height may lead to inconsistencies.


It is shown that the A2 supergiant α Cygni has a depth dependent microturbulent velocity in its atmosphere which varies from 7.8 km/sec at $\tau = 0.5$ to 20 km/sec at $\tau = 0.05$. The lines in the spectrum indicate a macroscopic velocity of 22 km/sec. This motion is described as a sequence of irregular pulsations.


The spectrum of Y Ser is analyzed and it is concluded that agreement between the abundances derived from lines of neutral atoms and ions can only be obtained by assuming the existence of
a depth dependent microturbulent velocity. This assumption is supported by curves of growth. Fitting the model to observations then gives values for the effective temperature, the surface gravity and the variation of microturbulent velocity with depth.


The propagation of a shock wave in an inhomogeneous stellar atmosphere has been studied. It is found that, while the shock decays if the distance traveled by it is less than or of the order of the scale height of the atmosphere, it gains in strength otherwise.

Calculation of the Outer Convection Zone with Non-Local Mixing;

The mixing length theory of turbulent convection with a non-local density scale height is applied to calculations of models for the outer convective zone of the sun and of a red giant of 1.3 M☉. The structure of the zone must be calculated by iterated integrations through the whole zone. Near the outer boundary of the giant's convection zone the convective velocities are found to be close to the velocity of sound.


The spectrum of the high velocity star HD 161817 is analyzed using model atmospheres in non-gray radiative equilibrium. Among other things, the velocity of microturbulence is found to increase from 2 km sec⁻¹ at the surface to 4 km sec⁻¹ at an optical depth τ = 1.


Theoretical profiles of the emission lines appearing in envelopes formed as a result of ejection of matter from a star are considered. The emission and absorption components of a bright line are investigated separately. Line profiles are studied for envelopes in which matter moves with constant velocity and with radial acceleration for the limiting cases of totally opaque and transparent envelopes. The theoretical profiles are very similar to those observed for the Wolf-Rayet and P Cyg-type stars and novae.


Equations are obtained for the shock adiabatic and the parameter discontinuities at a stellar shock wave front moving in a gas-radiation mixture. When one includes radiation loss terms in the equations, this leads to an increase in the density discontinuity and a noticeable decrease in the temperature discontinuity compared with results obtained from the classical Rankine-Hugoniot theory.

An expression is derived to determine the growth time for build-up in radiation intensity prior to the emergence at the surface of a medium of constant density of a shock wave moving with constant velocity. The time required for the brightness to build up to maximum is extremely short. For example, for \( n = 10^{12} \text{ cm}^{-3} \) and \( V = 100 \text{ km sec}^{-1} \), this time is of the order of \( 10^{-2} \text{ sec} \) in the continuum and is even shorter in the line. As the density of the medium decreases, the growth time increases rapidly.


The problem of the profiles of bright lines is considered in the case where an efflux of matter from a star is accompanied by a deceleration inside the extended "reversing layer," assuming a power law of variation for the rate of efflux. The absorption and emission components of the bright line are studied separately. When the flowing matter is opaque, the findings differ qualitatively from those yielded by the analogous theory of efflux at a constant rate accompanied by an acceleration. The resulting profiles constitute a multiplicity of complex forms. Application to the star, Mira Ceti, shows that the splitting of the bright lines \( H_\gamma \) and \( H_0 \) may be explained using this theory.


A criterion for the spontaneous appearance of hydromagnetic turbulence for the time-independent and time-dependent cases in stellar atmospheres is given. This criterion is applied to the turbulence associated with the solar granulation. Richardson and Schwarzschild's observations are interpreted as a time-average of time-dependent turbulence. The effective mean magnetic field intensity is estimated and is in essential agreement with Babcock and Babcock's observations.


The condition for the onset of convection is studied for polytropic atmospheres in which both the viscosity and thermal conductivity coefficients are assumed to be constant. A polytropic variation for the disturbance is assumed and a non-dimensional number characterizing the condition of marginal stability is computed for the most unstable mode using the variational principle. Computations of actual atmospheric models show that the critical horizontal wave number depends very little on the density variation.


As a further extension of their first paper (1960) to determine
the effect of density variation on the critical horizontal wave number for convection, the authors compute this value and the associated critical Rayleigh number for atmospheric models having large variations in density (but not in temperature) and also variations in viscosity and thermal conductivity. The effects of the Coriolis force associated with stellar rotation and of the penetration of convective elements into the upper stable layer are also considered. When the unstable layer extends over many times the scale height, the horizontal eddy size is confined to be much smaller than the layer thickness, while the vertical asymmetry of the flow pattern depends on the variation of viscosity and thermal conductivity with height. Results obtained by the Boussinesq approximation of incompressibility are approximately valid if the layer does not extend beyond three times the scale height. The Coriolis force increases the value of the critical Rayleigh number while the effect of penetration decreases it.


The effects of radiative cooling on the structure of a shock wave moving outward in a plane parallel stellar atmosphere are considered. The equations of hydrodynamics and radiative transfer are solved simultaneously, assuming the shock wave to be semi-stationary and the LTE conditions to apply everywhere. The shock structure emerges as a function of the undisturbed density and temperature, the shock velocity relative to the plane surface boundary and the optical thickness, \( \tau_f \), of the shock front. The results of calculations show that the height of the temperature peak behind the shock front is rather insensitive to \( \tau_f \) but that the effect of radiative cooling is conspicuous. The final temperature drops considerably below the value predicted by the classical Rankine-Hugoniot relations for small values of \( \tau_f \). Finally the density ratio can become greater than the \( (\gamma + 1)/(\gamma - 1) \) limit of the Rankine-Hugoniot theory.


An effective Reynolds number of 30 is estimated for steady convection in a stellar envelope from observations of laboratory experiments with turbulent flows. This value leads to an eddy viscosity which makes the linear theory of steady convection equivalent to the mixing length theory. The turbulence spectrum for large eddy elements obtained from the present simple theory agrees with results from the theory of Ledoux, Schwarzschild, and Spiegel.


The condition for the onset of convection is studied for the double layered model consisting of an upper more unstable and
lower less unstable layer. For a Boussinesq atmosphere of constant viscosity and thermal conductivity, the critical Rayleigh number and the flow pattern are calculated for several cases having different ratios of super-adiabatic temperature gradients and of thickness between the two layers. Elongation of convective cells in the vertical direction is discussed.


An exact asymptotic form of convective growth-rates for large horizontal wave number elements is derived analytically for a polytropic atmosphere without viscosity and conductivity. Results apply to the outer convection zones of late type stars.


The propagation of a stationary shock wave with interaction with the radiation field in LTE is considered. A method for computing the propagation through a succession of stationary states is proposed and a numerical example calculated. It is shown that the wave structure undergoes considerable changes due to radiation losses from the region behind the shock front but that the motion of the front is insensitive to such effects.


The familiar Brinkley-Kirkwood theory of shock propagation has been extended to take into account the inhomogeneity of the undisturbed region confronting the shock. It is concluded that the concept of shock strength must be used with care in this case.


The generation of acoustic noise in a turbulent, infinitely extended, isothermal atmosphere is studied where density stratification results from gravity. In such atmospheres, the sound wave mode interacts with the turbulence even in the linear theory. The power of the emission from this linear interaction depends on the decay of the correlation between different turbulent velocities. Recent observations of the solar granulation are discussed in connection with these results.

On the Criterion of Schwarzschild; Souffrin, P. M.; C. R., 252, 2073, 1961.

The criterion of Schwarzschild concerning the necessary condition for convective instability in a stellar atmosphere is shown to be based in part on a somewhat erroneous phenomenological dynamical model. A correct derivation of the instability condition using the equations of hydrodynamics still yields the Schwarzschild criterion, however, as well as an additional necessary condition which can be used to explain certain differences in the results of Skumanich and of Böhm and Richter on this general problem.
Model of Stellar Convection Zones; Souffrin, P. M.; C. R., 252, 2997, 1961.

A dynamical model for stellar convection zones is proposed in which the convection zone consists of a polytropic layer bounded by two semi-infinite, isothermal, convectively stable zones. It is shown that this treatment is completely unrestrictive if the convection zone is sufficiently thick.


This summary article considers the role of convection, and particularly hydromagnetic convection, as a means of transporting energy from the stellar interior to the atmosphere. Although no original work is reported for the first time, the article provides an excellent review of current ideas.


A hypothesis that a planetary nebula could arise from a catastrophic explosion of a red giant star when helium burning begins in the degenerate helium core is proposed and examined critically. A shock wave would be generated by rapid core expansion caused by the removal of degeneracy in the core. The shock propagation through the star is examined. Values are obtained for the expansion velocity and the mass value of the ejected material. A comparison is made between the remnant star and nuclei of known planetary nebulae.


The ejection of shells by slow shocks in stellar envelopes is considered.


The variation of velocity of expansion with distance in stationary supersonic flow with radiative cooling is studied.


The turbulent velocity is found to be growing with height.


The variation of turbulent velocity with optical depth is studied.
A method for calculating the change of shock strength is given.

The shocks with radiation are considered.

There are changes in the character of the motion in the envelopes of Tau and HD 217050 for small variations of the size of the envelope.

The character of the dependence of microturbulent velocities on spectral class is examined. Two maxima in this dependence may be connected with the variations of the depth of the convective zone and the depth of formation of spectral lines.

An analysis of the Hα profile does not confirm the presence of motions with v = 1000 km/sec as has been suggested.

The lines of neutral atoms are not shifted relative to ions' lines.


A review of observational data.


Mass Ejection from the Late Giant Stars; Publev, S. V.; Voprosy Kosmogonii, 10, 119, 1964.
A criterion for the polytropic stationary outflow is developed. The photospheres of late stars cannot be in macroscopic equilibrium. Too high estimates for mass ejection are obtained.


The results of calculations with an electronic computer for the models with \( n = 1.5 \) and \( n = 3.0 \) are given.
VARIABLE STARS


BL Herculis exhibits features which can be explained by the passage of an outward-moving shock wave which forms a moving, hot, strongly radiating region. Resulting luminosities agree well with observed luminosities of globular-cluster variables of similar period.


The RR Lyrae-type variables SU Dra, VY Ser, and AP Ser were investigated spectrographically in an effort to establish the variations in their radial velocities.


Analysis of Fath's photometric measurements of the variable star Delta Scuti shows three related periods excited in this star: the fundamental, the second overtone, and the resonance period. A similar treatment of Paddock and Struve's radial-velocity measurements yields similar results for the light variation. Maximum light precedes maximum expansion velocity by about 0.07 period for all three cases. Approximate equations are given for radial-velocity and light variations.


A program of numerical calculations is described in which one tests the suggestion that second helium ionization occurring at a critical depth in a stellar envelope is the ultimate source of cepheid instability. It is concluded that the results are generally favorable to the hypothesis, if applied to population I cepheids. Because of various uncertainties, however, the conclusion must be regarded as tentative.


Measurements of the projected rotational velocities of eleven β Canis Majoris variables are presented. The average rotational velocity of these stars is much less than the value for non-variable stars of similar spectral type and luminosity class, suggesting that high rotational velocities inhibit the pulsation of stars.


Evidence indicates that the early F-type subgiant τ Cygni may be variable with a period of about 3.6 hours. This is particularly interesting as τ Cygni then becomes one of a very exclusive class of observed objects, a rapidly rotating, pulsating star.

From determinations of the radial velocities an effort is made to classify this variable star. No firm conclusion is reached, but the evidence seems to rule out classification as a β Canis Majoris variable or a binary star.


The purpose of this study was to refine previous efforts of the author and others to test the hypothesis that HeII ionization in the envelope is the source of the instability in cepheid variables and possibly other types of pulsating stars. Numerical solutions of the complete set of linearized, non-adiabatic pulsation equations have been obtained for a large number of simplified stellar envelope models in radiative equilibrium. The author concludes that, among the models chosen, those which satisfy a critical condition on the equilibrium radius (which depends on L and M) are possible models of real pulsating stars. When plotted on the HR diagram, the locus of these critical models corresponds rather well to the locus of actual pulsating stars and the periods are nearly the same. Thus HeII ionization in the envelope seems a likely source of pulsational instability, particularly in classical cepheids and RR Lyrae variables.


The beat phenomenon in which two radial oscillations of nearly equal period occur is studied for several β Cephei stars. It is first noted that this phenomenon occurs in those stars showing the highest projected rotational velocities of the group, namely 30 to 60 km sec⁻¹. Following a suggestion by P. Ledoux, the author considers the possibility that the occurrence of the two periods may be connected with rotation. After a brief analysis based on recent work by Chandrasekhar and Lebovitz on the possible oscillations of a rotating compressible sphere, the conclusion is that the mechanism exciting the beat phenomenon is strongly influenced by the rotation and may be the rotation.


A numerical procedure is developed for calculating the dynamical pulsation and luminosity variation of RR Lyrae and Cepheid type variable stars. The procedure promises to elucidate the mechanism responsible for the pulsation. Particular care is given the treatment of the opacity and equation of state in the envelope region where pulsations seem to arise. A sample calculation is performed to illustrate the method. No firm conclusions are obtained regarding the pulsational mechanism, but further applications to typical pulsating star models should relieve this problem.


The adiabatic radial oscillations of a ten solar mass model of
an early main sequence star have been studied. Characteristic
frequencies and the relative amplitudes for the first four modes
have been obtained. The pulsational stability of the star has
been considered also, including only the first four modes.

Pulsational Properties of an Early Main-Sequence Star. II; Gurum,
The anharmonic pulsations of an early main sequence stellar
model have been studied. It is found that a better approximation
to the skewness in the radial-velocity curve is obtained in this
way.

The Atmosphere of κ Pavonis. II. Line Profiles; Bell, R. A.,
High dispersion spectra of the cepheid κ Pav are used to
obtain profiles of the lines λ4508 Å of FeII and λ4427 Å of FeI.
The variation in the line breadths can be interpreted as a change
in rotational velocity from 11 to 34 km sec⁻¹. Alternately, the
variation may be regarded as a change in macroturbulence. In
the latter case, there would be a correlation between macro- and micro-
turbulent velocities.

Study of Some Nonradial Oscillations of the Roche Model; Ottelet,
A study of nonradial oscillations of the Roche model star
with Γ = 3/2 is described. In particular, the characteristics
of the perturbations causing the model to become dynamically un-
stable are determined. There appears a brief discussion of the
relationship between two dimensional, nonradial oscillations and
the nature and stability of a convective envelope in the model.

On the Period of Radial Pulsation of the White Dwarfs; Schatzman,
Computations of the period of radial pulsations of white
dwarfs are made for different values of an internal structure
parameter 1/Y₀² first introduced by Chandrasekhar. A comparison
with previous work is provided.

A Statistical Study of the Light Curve of the Variable Star SS
The author discusses the dynamical origin of the explosive
changes in the light curve of this variable double star after
performing a very thorough statistical analysis of the brightness
fluctuation.

Observations and Interpretation of the Variable Star SS Cygni;
A study of the possible mechanisms involved in the explosive
changes in the observed light curve of this double star suggests
a strong similarity to the mechanisms involved in novae and
supernovae explosions.
A careful study of the profiles of absorption lines formed in the reversing layers of cepheids leads to the conclusion that these profiles cannot be explained if one uses the simple model of a single velocity reversing layer. A more sophisticated radial velocity distribution in the reversing layer is required.

The effects of the energy exchanges associated with convection in the extensive central cores on the vibrational stability of massive stars are considered for two extreme cases: convection adapts itself instantaneously to the pulsation or it does not. In the first case, rather unlikely as the pulsation period is much shorter than the mean lifetime of a turbulent element, the net effects are negligible. In the second case, convection has a clearly destabilizing influence but, quantitatively, this remains small and reduces the critical mass by, at most, ten percent.

The vibrational stability of Kruger 60 Å with respect to the fundamental mode of radial pulsation is investigated and it is shown that the star is vibrationally unstable if the influence of the atmospheric layers in radiative equilibrium is neglected. A preliminary analysis of the effects of a radiative atmosphere suggests that the latter only reinforces the instability. Thus it seems justified to conclude that red dwarfs essentially in convective equilibrium throughout are vibrationally unstable.

An equation of motion for a pulsating gas sphere is derived and an integration theory for solving it worked out. It can be used for predicting the pulsations from some physical cause or analyzing observed pulsations. It provides some necessary conditions for both the assumptions of the physical cause of pulsation and the structure of a pulsating star in equilibrium.

A report of the light variations of ν Eridani suggests a complicated oscillatory behavior in which those oscillations having nearly equal periods appear to have differing spatial behavior inside the star and to influence one another in amplitude and frequency. The star thus behaves like an oscillating system with a non-linear characteristic function. The oscillation that produces the periodic broadening of the spectral lines is apparently the fundamental one.

The various oscillations in the radius of \(\nu\) Eridani can be accounted for by noting that maximum compression corresponds to maximum brightness except for a small shift which can be explained. Reasonable values for the radius are derived from the various oscillations, assuming that they are purely radial pulsations.


Model envelopes in hydrostatic equilibrium have been integrated for five population I stars in and near the \(\delta\) Cephei region of the Hertzsprung-Russell diagram. Linearized time-dependent equations representing radial pulsations of these equilibrium models were solved numerically to determine whether a small radial distortion decreases (stability) or increases (instability) with time to make the star pulsate like the observed cepheid variables. It is found that a star in the \(\delta\) Cephei region \((M = 11.5 M_\odot, L = 5000 L_\odot, T_C = 5390^\circ K)\) having a period of 6 days is pulsationally unstable due to the destabilizing effect of the He II ionization region.

Multiple Periods in \(\beta\) Crucis; van Hoof, A.; Zs. f. Ap., 54, 244, 1962.

The analysis of the light and radial velocity curves of this \(\beta\) CMa star reveals several overtones and resonance oscillations besides the fundamental one. The fundamental period appears different from one proposed previously by Pagel whose value seems to correspond to the first overtone. The ratios of the various periods to the fundamental are consistent with a polytropic structure of index 3 and \(\gamma_1 = 1.532\).


Overtones and resonance oscillations present in the light variation of \(\theta\) Oph are analyzed and periods and amplitudes determined for eight of them observed in UV light. The ratios of the overtone periods to the fundamental period are consistent with a polytropic star of index 3 and \(\gamma_1 = 1.513\).


The observed variations in the period of \(\beta\) Cep can be traced to more than one hundred oscillations, all of different periods. These have been identified as the pulsations in the successive overtones, up to the tenth, and as those alien frequencies predictable from the presence of terms to the second and third power of the displacement in the equation of motion. The absence of line broadening is attributed to the weakness of the fundamental mode.


At least twelve different oscillations are present in \(\beta\) CMa. These are identified and the probable structure of this variable star is indicated.

It is shown that the observed phase relation between the radial velocity and brightness curves of \( \delta \) Cephei can be attributed to the onset of convection at the instant of maximum instability in the convection zone.


The structure of the H\(_{\alpha}\) emission lines and their variations from 1957 to 1961 have been measured. These and other observations of Cyg suggest that the supergiants of earlier spectral types perform irregular pulsations of a higher order. The dissipation from such pulsations could form a type of chromosphere made up of gas clouds of irregular structure and velocity.


From the curve of growth obtained from measured intensities of H and HeI, the turbulent velocity in the atmosphere of P Cyg is calculated to lie between 21 and 24 km sec\(^{-1}\).

Multiple Periods in \( \xi^1 \) Canis Majoris; van Hoof, A.; Zs. f. Ap., 56, 141, 1962.

For a \( \beta \) C Ma star with known fundamental period \( P_0 \), it is shown how to predict the ratios \( P_1/P_0 \). In the case of this particular member, an evaluation of the radius shows that the oscillations are no longer adiabatic in the outer portions of the star.


The author provides strong arguments favoring the current tendency to divide supernovae into two basic classes, I and II, by showing that they appear to differ in kinetic energy of expansion, luminosity and underlying mechanism responsible for the initial explosion.


A five year discrete model for a stellar envelope is constructed such that its quasi-adiabatic oscillations correspond to those in the continuum distribution and its non-adiabatic oscillations are described in great detail in that part of the envelope experiencing great variations in the phase and amplitude of the radiation. Comparing several models elucidates the effects of the helium content and other parameters on the phase and amplitude of the emergent radiation.


The profile on an absorption line formed in an expanding
envelope with a velocity gradient is constructed, assuming the profile of the absorption coefficient to be of Doppler form.


Arguments are advanced disputing the analogy between the formation of the phase-shift of luminosity relative to radial variations for pulsating stars and the known phenomenon of formation of the time-lag of thermal waves propagating in a nonpulsating medium. This analogy, first noted by Eddington and developed by Rosseland, leads to a formula for the phase-shift of variable stars used by Cox, and Whitney and Cox, to study the period-luminosity relation for classical cepheids and population II cepheids. The author contends that some of the conclusions of Cox, et al., are wrong, due to the use of the erroneous phase-shift formula.

Motion of an Envelope of Variable Mass; Minin, I. N.; USSR AJ, 37, 939, 1960.

It is shown that the motion of an envelope through the interstellar medium of density \( \rho_c \), under the assumption that the mass of the envelope increases continuously at the expense of the interstellar medium as well as by outflow of matter from the star, can be treated in an elementary way without resorting to numerical integration.


Several arguments show that if the pressure of cosmic rays in a system is greater than magnetic forces and gas pressure, the system cannot be in stable equilibrium. Cosmic rays are retained in the shells of supernovae and their pressure is high at the boundary, where the mass of the shells is also concentrated. It is shown that if the magnetic field is tangential it creates an instability where the field is forced out by cosmic ray pressure in the form of separate loops, taking with it the gas which moves along the warped magnetic lines of force to form filaments.


The development of hydrogen emission lines in the spectrum of a long-period variable star is discussed, assuming that simultaneously with increase in brightness a shock wave is propagated with increasing velocity through the atmosphere. The shock wave velocity is estimated from the displacements of bright lines. The process of ionization behind the shock front is studied. The time of exhaustion of energy of a layer compressed by the shock wave is estimated. The observed deceleration of the emitting layer is attributed to gravity.

Observations made by Sanford of radial velocities of RR Lyrae are interpreted. The observed splitting of the spectral lines and hydrogen emission on the short-wave side of the Hα line are analyzed as effects of a shock wave propagating through an isothermal atmosphere at rest in a uniform gravitational field. Analyzing the Hα behavior using this model yields for the effective gravity, 40 cm/sec^2, the atmospheric temperature, 5500°K with the photospheric temperature exceeding 8000°K, and the hydrogen concentration, 10^12 cm^-3, in the lower atmospheric layers where the Hα is formed.


Mechanisms which can lead to the replacement of the premaximum spectrum of novae by the principal spectrum are considered. The author first considers the following proposed accelerating mechanisms of the ejected gas: shock wave, gas condensations, radiation pressure, a continuous ejection of gases whose velocity and intensity vary strongly at light maximum. Arguing from existing observational data, he rejects all of these and concludes instead that the main accelerating force for the detached envelope is cosmic ray pressure. It is argued that the intermediate cavity formed between the envelope and the star is filled up by cosmic rays.


The motion of a nova envelope during the period from light maximum to the nebular stage is considered, assuming that corpuscular radiation ejected from the residual star is the accelerating mechanism. The law of motion for the envelope is obtained and the problem is solved in a one dimensional approximation. It is shown that the law of motion is rather insensitive to interactions among particles of the corpuscular stream. Also departures from spherical symmetry in the ejected envelope or the direction of ejection of the corpuscular stream are found to lead to envelope breakup into discrete clouds, an effect which has been observed in some cases.


A numerical integration of the partial differential equations describing a spherically symmetric model of a nova outburst is performed. The equilibrium models with polytropic indices of 1.5 and 3 are subjected to a disturbance which gives rise to a strong shock wave. It is found that, when the wave breaks through the surface, a portion of the matter acquires sufficient velocity to form an expanding shell. The relationship between the kinetic energy of the shell and its mass yields also the original mass of the nova. Mass values of the order of 0.02–0.2 M☉ are found for slow novae and mass values of the order of several hundred solar masses are found for fast novae.


These two short papers, which appear in the Letters to the Editor section, should be considered together. They represent the feelings of the three scientists regarding a criterion for pulsational instability which, if valid, will considerably clarify and simplify the problem.

The Pulsation of Rotating Stars; Porfir'ev, V. V.; USSR AJ, 40, 579, 1963.

Absorption line profiles are computed for a star, assuming the presence of radial oscillations superposed on a variable meridional circulation. It is concluded that the profiles obtained can be used to interpret spectral-line profiles of Beta Canis Majoris stars.

Note on the Nature of Beta Canis Majoris Variables; Olünik, G. T., Porfir'ev, V. V.; USSR AJ, 40, 774, 1963.

A new hypothesis on the nature of B C Ma-type variable stars is discussed. It is assumed that these stars undergo radial oscillations which are in turn responsible for the variable meridional circulation or rotational oscillation. It is shown that the proposed scheme is completely in accord with the evolutionary scheme of B stars advanced by others.


The qualitative theory of a supernova explosion, in which an implosion of the core causes an enormous sudden increase in internal and kinetic energy of the envelope through the release of gravitational energy, is made more quantitative through use of a shock wave propagation theory developed by the authors. Some general features of a supernova, such as the quantity of mass expelled and its expansion velocity are determined from the ratio of initial stellar mass to radius. A comparison with some observational results is provided.


A stellar model with a convective envelope and a partially degenerate isothermal core corresponding to a long period variable star has been computed. Reasonable values are chosen for the mass, effective temperature, and radius. The vibrational instability is supposed to be caused by HI and HeII ionization in the envelope. Results show that this ionization occurs at $0.2 < r/R < 1$ and that the convective envelope extends down over 90% of the radius. The adiabatic and simplified non-adiabatic pulsations of the model are studied. Periods are in fair agreement with data on long period variables.

Assuming that the oscillation is excited in two layers of a long period variable star (HeII and HeI + H I layers), the author concludes that a possible cause of the irregular variability observed in the period of pulsation may be the nonlinearity inherent in the mechanism of negative dissipation in the two layers.


It is estimated that partial pressures of several gaseous molecules in the atmospheres and circumstellar envelopes of M type, long period variable stars will exceed their saturation vapor pressures and that solid particles composed mainly of SiO2 will be formed. When removed from the vicinity of the star by outflowing gas streams, water vapor is expected to cling to these particles. The icy particles formed are thought to be the observed interstellar grains.


The problem of the propagation of disturbances inside of variable stars is considered in its general aspects in an effort to improve upon older analytical techniques for treating the pulsations which sought individual oscillations satisfying the boundary conditions rather than an assembly of modes whose net effect is the observed pulsation. The use of electronic computers to solve the more general problem is discussed.


The equation of propagation of a shock wave in a form suitable to a spherically symmetric medium is given, and it is applied to a series of models. It is shown that the outer zones of stars are unstable for the propagation of shock waves while the central zones are stable. Near the surface of separation there is stability or instability depending on the model. The minimum amplitude for which one can speak of a shock wave is discussed. Results are compared with observational data on variable stars.


The study of the spectrum of H.D. 218393 suggests a stratification in the envelope due to the important differences in radial velocities between different elements and a positive progression of the Balmer lines of hydrogen.

Spectral Variations of H.D. 50138 Observed with Large Dispersion; Doazan, V.; C. R., 254, 222, 1962.

Spectral observations of H.D. 50138 are discussed. The principal absorption in the lines shows a slow variation of radial
velocity whereas a secondary absorption shows rapid displacements. Together, these absorptions suggest a variation of V/R of the emission components similar to what is observed.

Spectral Variations of H.D. 45910 Observed with Large Dispersion; Doazan, V.; C. R., 254, 827, 1962.

The variations in the velocities of the principal absorption lines of hydrogen suggest a period of 38.5 days. Also reported are variations in the velocities of some lines of FeI which differ from those of hydrogen in such a way as to support the view that the system is a binary. However, the orbital motion cannot explain the structural variations in the spectra unless one of the members is a variable star.


The radial velocity of the envelope of τ Tauri is determined for the period 1961-63. Certain peculiarities are discussed.


Gasodynamical equations and, especially, the shock relations are examined in an attempt to deal with violent dynamical phenomena of stars. The propagation of shock waves in stellar interiors and atmospheres is discussed. An application of an original method is made to a supernova explosion.


The enormous amount of energy released from rapid nuclear reactions occurring after the collapse of the core of a massive star generates a shock wave which propagates outward ejecting a large amount of material from the star at a high velocity. The rate of energy generation, the total amount released and the behavior of the shock wave, particularly regarding escape of radiation when it reaches the stellar surface are all calculated for a late stage giant star of mass 15.6 M☉. The maximum luminosity, maximum temperature, width of peak of light-time curve at maximum luminosity and velocity of expansion for ejected matter all agree fairly well with observational data for Type II supernovae.


The authors propose that cosmic rays originate in supernova explosions. Included in their development are discussions of the mechanism of the explosion, the hydrodynamic motion following the explosion, the structure of relativistic shock fronts and the subsequent flow of radiation.


Flares of EV Lac and BD +5102402 were observed with blue and yellow filters. Light curves and some other characteristics are given.

