AN EXAMINATION OF THE OBSERVATIONAL EVIDENCE FOR THE ACCRETION THEORY OF THE SOLAR CORONA

D. E. Blackwell and D. W. Dewhirst

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Summary

The predictions and requirements of the accretion theory of the solar corona are compared with the results of observation, with special reference to the electron distribution in the neighbourhood of the Sun and convection in the inner corona. It is concluded that, even with reasonable modification, the theory is unable to satisfy the requirements of observation, and that accretion is therefore not likely to be an important coronal mechanism.

1. Introduction.—The theory of the accretion of interstellar gas by stars has been developed in papers by Bondi, Hoyle and Lyttleton (1, 2, 3, 4), and these authors have applied the theory to the solar corona (5, 6). McCrea has given a valuable survey of the status of the general accretion theory as it appeared in 1953 (7). It is likely that the accretion process is an important one in astrophysics generally, but its importance in solar physics has never yet been adequately discussed. Criticism of the accretion theory and of its application to the Sun has been made, on theoretical grounds only, by Atkinson (8), Öpik (9), Pikelner (10) and Gething (11), and there has been further discussion of some general points by Hoyle and Lyttleton (12), and by others at the conference on cosmic clouds held in Cambridge in 1953 (7). In a later publication Hoyle (13) has developed the accretion theory and presented more observational material to support it, without altering the essential form of the theory as it was proposed in 1947 (5). However, in this paper we shall attempt to assess the value of this theory of the corona by a more rigorous comparison of its predictions with the results of observation, using new data concerning the electron density in the neighbourhood of the Sun which have recently become available. Except for some criticisms by van de Hulst (14), we feel that comparison with observation has hitherto been inadequate and it now seems opportune to review the situation. In making a comparison it is necessary to remember the basic assumptions in the theory, and to make a final assessment we need to consider all reasonable modifications of it.

We are here concerned primarily with investigating the plausibility of the accretion mechanism as a solution to the problems of the corona. In addition, however, we may think of the solar neighbourhood as the most suitable testing ground for the accretion process in general astrophysics.

The relation of the observations to other theories of the corona has not been examined by us in this paper, and we do not wish to imply, by this omission, that they do not have difficulties.

2. The accretion theory.—Broadly speaking, the solar corona can be described as a hot and optically thin atmosphere, not in radiative equilibrium with the photosphere: its temperature is about 10^6 degrees. While there are features
of coronal structure which are still far from being understood, e.g. the fine structure of the inner corona, the chief problems are to understand the mechanism which maintains the high temperature of the inner parts, the reason for the great extension along the ecliptic, and the forces which so closely link the shape of the corona with the phase in the sunspot cycle. The accretion theory supposes that the energy for the maintenance of the coronal temperature comes from the gravitational energy of accreted gas, and that this gas is observed in the outer parts of the corona. The following is a summary of the theory based chiefly on references (5, 6, 13).

The Sun is supposed to be moving with velocity \( v \) through an interstellar gas cloud, which is chiefly hydrogen, containing \( \tau_{\infty} \) atoms cm\(^{-3}\). What happens when the Sun first enters this cloud is not clear, but it is supposed that after a short time an equilibrium state is reached. A tail is formed behind the Sun which traps hydrogen atoms or ions passing through it by reducing their transverse velocities. If the remaining radial velocity of an atom, after collision at a certain position along the tail, is less than the escape velocity from the Sun at that point, the atom will return to the Sun along an undetermined path and be captured.

This is a mechanism for converting a hyperbolic orbit into a parabolic or elliptical orbit. Three simplifying assumptions are now made. First, the gas pressure is never so great that pressure effects have to be taken into account; second, the flow of accreted atoms into the Sun is radial for all distances from the Sun of less than 1 A.U.; third, the effects of magnetic fields of solar and interplanetary origin are neglected. If \( M \) is the mass of the Sun and \( G \) the constant of gravitation, and all the interstellar gas within a distance \( a \) of the Sun is captured,

\[
\frac{2MG}{v^2} = \sigma.
\]

Further, the rate of accretion of hydrogen atoms by the Sun is

\[
\frac{dN}{dt} = \frac{4\pi G^2 M^2}{v^3} \tau_{\infty}.
\]

When the Sun first enters the cloud the accreted material increases the temperature of the Sun's outer parts to form a more extended atmosphere. Further atoms on arrival are increasingly retarded by collision as they pass down through this atmosphere, until an equilibrium state is reached in which, at a distance \( r^* \) from the centre of the Sun, their momentum has been reduced to a fraction \( 1/e \) of its original value. For convenience, those atoms which still retain most of their momentum are called "accreted" atoms, whilst those which have undergone numerous collisions in this inner zone are called "solar" atoms. By making assumptions about the rate of loss of energy by impact, \( r^* \) is calculated to be \( 1.17R_{\odot} \); that is, most of the energy of the incoming atoms is lost at a distance of about \( 0.17R_{\odot} \) above the photosphere. It is shown that at this distance the density of incoming atoms is small in comparison with the density of atoms belonging to the solar atmosphere.

Besides providing energy, the incoming atoms transfer downward momentum to the solar atoms and in this way effectively increase the value of the gravitational acceleration. Let the density of accreted atoms at distance \( r^* \) be \( \tau \) and let there be \( N(r^*) \) solar atoms in a column of cross-section 1 cm\(^2\) above this level. Then it is shown (6) that, because of the collisions they suffer with the accreted atoms,
the solar atoms are subjected to an effective gravitational acceleration \( g(1 + q) \), where \( g \) is the undisturbed gravitational acceleration due to the Sun, and

\[
q = \frac{\tau V^2}{gN(r*)}.
\]

\( V \) is the velocity that an atom acquires at distance \( r* \) in the gravitational field of the Sun

\[
V = \sqrt{\left(\frac{2GM}{r^*}\right)}.
\]

Much of the attraction of the theory arises from the numerical value of \( V \), 570 km sec\(^{-1}\). This allows ample margin to account for a supposed r.m.s. velocity of hydrogen atoms in the corona, namely 90 km sec\(^{-1}\) at 10\(^6\) degrees.

From a comparison of the observed values of electron density in the chromosphere and corona with the computed values for various values of \( q \), Hoyle deduces that \( q = 0.25 \). Hence he deduces \( \tau \), the density of the incoming atoms. Now, as it is assumed that all of the atoms contained within a cylinder of cross-section \( \pi a^2 \) are swept up by the Sun and produce a density \( \tau \) near the surface, we can calculate the density of hydrogen atoms at distance \( r \), considered to be the density at distances from the Sun large in comparison with the size of the solar system. Hoyle (6), assuming \( v = 10 \) km sec\(^{-1}\), derives

\[
\tau_r \sim 45 \text{ atoms cm}^{-3}
\]

which is regarded as "well within the range given by studies of galactic structure and stellar evolution". In ref. (13) the value \( \tau_r = 30 \) atoms cm\(^{-3}\) is also given.

The kinetic energy of the incoming atoms is liberated by collision, chiefly at the height of \( 0.17 R_\odot \) above the photosphere, and it has now to be dissipated. According to Hoyle (6) dissipation by radiation or conduction is completely ineffective, and he therefore postulates a powerful system of convection currents operating between this layer and the photosphere. It is shown that the velocity of the downward current is of the order of 470 km sec\(^{-1}\) and that of the upward current is of the order of 750 km sec\(^{-1}\), both velocities being relative to that of the incoming accreted material.

We notice at this stage that if this analysis is correct the total flux of energy into the corona from the accretion process is apparently much greater than is necessary to maintain the corona. The most reliable estimate of the rate of loss of energy from the corona is about \( 1.4 \times 10^{37} \) ergs sec\(^{-1}\) (15). As 80 per cent of this energy loss is by conduction down to the photosphere, it is unlikely that this estimate will be greatly affected by uncertainties in the amount of radiation in the far ultra-violet. The total flux of energy from accretion is

\[
\frac{1}{2} m_p V^2 \frac{dN}{dt} = \frac{4\pi G^2 M^2 m_p}{R_\odot^3} \tau_{\infty} = 0.71 \times 10^{37} \tau_{\infty} \text{ ergs sec}^{-1},
\]

where \( m_p \) is the mass of the proton, and \( v \) is assumed to be 10 km sec\(^{-1}\). When \( \tau_{\infty} \) is taken to be 45 atoms cm\(^{-3}\) this flux of energy is greater than the loss from the corona by a factor \( \times 22 \). The unwanted energy is convected down into the photosphere.

* Recent advances in knowledge of electron densities in the neighbourhood of the Sun require a modification of the value of \( q \). We do not however calculate a new value because our later arguments are independent of a precise knowledge of this parameter.
In the following discussion we first compare (in Section 3) the requirements of the above theory (5, 6) with the results of observation, and then (in Section 4) see if this theory can be made more convincing by alteration of detail.

3. Comparison with observation.—In this first analysis we use the values of the parameters given by Hoyle (6) viz.

\[ v = 10 \text{ km sec}^{-1}, \]
\[ \tau_\infty = 44.8 \text{ atoms cm}^{-3} \]

giving

\[ \sigma = 3.82 \times 10^3 R_\odot = 17.8 \text{ A.U.} \]

The theory is concerned with numerical values of the density of interstellar hydrogen close to the Sun; observationally we can study only the electron density. To compare theory and observation we therefore need a knowledge of the degree of ionization of the interplanetary hydrogen as a function of distance from the Sun. There is no doubt that at distances of the order \(10R_\odot\) the ionization is virtually complete. At distances of the order of \(100R_\odot\) there is some uncertainty. Hoyle (6) has suggested a value of the order of 50 per cent; Öpik (9), using a value for the flux of ionizing radiation obtained from ionospheric studies, derives a value of 99.7 per cent at \(200R_\odot\). In the following discussion we assume, with Öpik, that the ionization is complete in the region which concerns us, but if the degree of ionization is not less than 50 per cent at \(100R_\odot\) from the Sun our arguments are little affected.

(a) The electron density near the Sun.—In the region of the corona where most of the accreted material is stopped by impact with solar material, one might expect a change in the gradient of electron density. Hoyle writes “Actually, such a region does exist, at about twice the photospheric radius from the centre of the Sun. The density of the material of the solar atmosphere falls off steeply at this distance” (Hoyle (13), p. 119). It seems to us that there is no observational support of any kind for this statement. It is true that the electron density varies with position angle in a rather irregular way, corresponding to the complex structure of streamers in the inner corona, but there is apparently no position within \(10R_\odot\) of the Sun where the electron density changes in the way suggested. Fig. 1 shows the gradient of electron density derived from the analysis of van de Hulst (16) for the equatorial regions at sunspot maximum: at this time there is little difference between the equatorial and polar regions. The change of gradient with distance is regular and there is no special anomaly either at \(1.17R_\odot\) or at \(2.0R_\odot\). At sunspot minimum in the polar regions there is no evidence for an abrupt change of electron density out to the observable limit of \(6R_\odot\): in the equatorial regions a marked change of gradient occurs only at about \(25R_\odot\) from the Sun (18). It is clear that there is no support here for the accretion theory.

(b) The electron density in the outer corona.—(i) The assumption that the flow of accreted material into the Sun is isotropic for all distances up to 1 A.U. is evidently an oversimplification. At sunspot minimum the electron density in the polar regions is considerably smaller than that in the equatorial regions. At \(6R_\odot\) from the Sun the electron densities are probably in the ratio of \(1 : 25\) (17, 18). Were the theory correct, most of the electrons at this distance would be accreted electrons, and it would seem reasonable to deduce that accretion in
the polar regions is negligible. But in spite of this the chromosphere still exists in the polar regions at sunspot minimum, and, for the extreme inner corona, the tables of van de Hulst (16) show only a small difference between the gradients of electron density at the pole and at the equator. The diagrams of the brightness of the 6374 A FeX emission line plotted by Waldmeier (19) show that there is often emission in this line at the poles near sunspot minimum: evidently the temperature of the corona here cannot be much less than $10^6$ degrees. However,

![Diagram](image)

**Fig. 1.**—Gradient of electron density in the solar corona. Data from van de Hulst, referring to the equator at sunspot maximum.

it may be reasoned that even if there is no accretion at the poles a corona would still be expected to exist there because of the known high thermal conductivity of these regions. But we notice now that in the absence of a magnetic field one may expect the difference in electron density between pole and equator to be appreciably diminished by diffusion in a time $2R_\odot/u$, where $u$ is the average thermal velocity of a proton in the corona: this time is of the order of 3 hours. In fact, the large difference in density appears to exist for at least 5 years during sunspot minimum. There is therefore some force preventing mass diffusion along the density gradient from the equator to the poles. If mass diffusion is inhibited then thermal diffusion must also be inhibited.

Accretion, if the dominating mechanism, must somehow be reduced near the poles. It is tempting to link this with the presence of a general magnetic field. There are three points here, however. First, a magnetic field of the dipole type might be expected to *increase* the rate of accretion of charged particles at the poles. Secondly, if a magnetic field is admitted to be responsible, an important factor has been omitted from the accretion theory. Thirdly, if, as the theory suggests, the electron density at $6R_\odot$ from the Sun is due solely to accretion why should this density change so markedly (over a range of 25 : 1) with the solar cycle?
The observational

(ii) The situation in the equatorial plane is no more promising. Near the Sun, in the region ordinarily observed at eclipses, the electron component of the corona is nearly symmetrical about the solar equator. But far from the Sun, in the zodiacal light region, it is more nearly symmetrical about the ecliptic. It has been shown (20) that between elongations 25° to 43°, corresponding to minimum distances from the Sun of 90$R_\odot$ and 146$R_\odot$, the angle between the axis of symmetry of the electron component and the ecliptic is probably less than 1°. At some distance from the Sun between 90$R_\odot$ and 160$R_\odot$, the axis of symmetry must change from the ecliptic to the solar equator, but the precise position is unknown. There is no correspondence at all between this observational picture and the picture presented by the accretion theory. The symmetry of the electron component about the ecliptic suggests that these electrons are at least semi-permanent members of the solar system. Even if the direction of motion of the Sun through the supposed gas cloud were in the plane of the Earth’s orbit it would be difficult to see how the observed symmetry of electron distribution could be produced.

(iii) An important piece of evidence quoted as being in favour of the accretion theory is the variation of electron density with distance from the Sun. The original theory assumes free fall with no pressure effects and no collisions with the solar atmosphere beyond about 2$R_\odot$ from the centre. In this case the electron density should vary with distance according to the law

$$N = k r^{-3/2}.$$  \hspace{1cm} (5)

The density of the accreted electrons at 1.2$R_\odot$ has already been found by assuming $q = 0.25$ (p. 639). This value may now be used to predict the electron density at any distance from the Sun. Originally, the electron densities predicted by the theory were compared with the Baumbach model of the corona. This much-quoted model, which took no account of the F (dust) corona, was essentially a summary of all measures available at the time of its construction twenty years ago; it must now be discarded in favour of more recent measures (17, 18, 20, 21) in whose reduction full allowance has been made for dust. Since observations show the K (electron) corona to be far from radially symmetrical, comparison with any theory assuming radial symmetry is of necessity somewhat artificial. In Fig. 2 we plot the observed electron densities near the ecliptic on the same diagram as the predictions of the accretion theory. Two predictions are given here. The upper line assumes with Hoyle (6) an electron density of $2.1 \times 10^6$ cm$^{-3}$ at 1.17$R_\odot$. Then at 20$R_\odot$ the predicted electron density is too great by a factor of $\times 13$, although at 150$R_\odot$ the discrepancy has been reduced to a factor of 2.5. If we fit the theory to the measures at 150$R_\odot$ the overall picture is naturally improved (middle line) but the observed gradient of electron density at 150$R_\odot$ is much less than is predicted. The observed electron densities of Fig. 2 have been calculated by making assumptions about the polarization of the F component. These assumptions have been varied as far as seems reasonable to give maximum and minimum values outside which the actual electron density is unlikely to fall (20), and these extreme values are plotted in Fig. 3 along with the two predicted curves already given in Fig. 2. Although predicted electron densities are nowhere more than three times greater than the observed values, there is a great difference between the observed and predicted gradients at 4$R_\odot$ and 150$R_\odot$. 

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(c) Convection in the inner corona.—The original accretion theory supposes that the whole of the solar atmosphere between the chromosphere and the part of the corona where most collisions occur is in violent convective motion. This motion is necessary to remove accretion energy from those parts of the corona where it is liberated and is shared by all parts of the region. It is nearly radial and attains shearing velocities of about 280 km sec$^{-1}$.
Here there is great disagreement with observation. According to Kraul (22) the width at half intensity of the 5303 \( \lambda \) line in the coronal spectrum at the height of 0.5' above the limb (\( \equiv 23000 \) km or 1.03\( R_\odot \)) is about 0.7 \( \lambda \). The measurements of von Klüber (23) show that up to a height of about 4' the width is of the order of 1 \( \lambda \). Waldmeier (24) has considered the possibility that the contour of the lines is due to the streaming of coronal material away from the Sun, and has carried through the necessary integrations along the line of sight. An extension of his computations shows that the whole of the observed line width can be explained as due to ascending and descending columns in the region with speeds of 47 km sec\(^{-1}\) relative to the Sun. In fact, it is probably not permissible to ascribe more than 10 per cent of the line width to motions of this kind, the remainder being due to thermal motions corresponding to a temperature \( \sim 2 \times 10^6 \) degrees. The maximum permissible convection is therefore* of the order of \( 7 \pm 5 \) km sec\(^{-1}\). Even remembering that Doppler broadening is not a very sensitive method of detecting convection currents normal to the photosphere, it is difficult to reconcile the observed widths of coronal lines with the powerful and slightly non-radial convection currents postulated by the theory. A more promising method of seeking evidence for convection normal to the photosphere is to look for proper motions of coronal material either in the 5303 \( \lambda \) line using a coronagraph, or in white light during eclipses. Van de Hulst (25) has reviewed the published information about these motions. With a coronagraph it is possible to see fine structure in the corona up to heights of about 0.3\( R_\odot \). Both Lyot and Waldmeier have reported coronal condensations which remain identifiable for periods of 6 hours or longer, during which time the features show small positional displacements with velocities only rarely in excess of 10 km sec\(^{-1}\). In eclipse studies in white light fans and arches higher in the corona have been followed for periods of up to 24 hours, and have shown little motion or change in shape. On the whole such motion as exists tends to be away from the photosphere. It is difficult to see how such structures could retain their identity for such long periods were they subject to shearing velocities of 280 km sec\(^{-1}\). Under these conditions a coronal condensation of diameter 10\( ^{\circ} \) would double its size in 30 seconds.

(d) The hydrogen density in the neighbourhood of the solar system.—In order to explain the order of magnitude of the observed electron densities in the corona and zodiacal light regions, even assuming that the capture process is perfectly efficient, the theory requires the density of interstellar hydrogen in the neighbourhood of the solar system to be not less than 30–45 atoms cm\(^{-3}\). We may enquire whether this value is a reasonable one.

The most generally accepted mean density of hydrogen in the galactic plane, based on observations of H\( II \) regions and on dynamical grounds, is about 1 atom cm\(^{-3}\). There is good evidence that the distribution is not uniform. There are indications that near the galactic plane the hydrogen is concentrated into clouds of density about 10 atoms cm\(^{-3}\) which occupy 7 per cent of interstellar space; between the clouds the density is not greater than 0.1 cm\(^{-3}\) (26). Both optical and 21 cm measures show that the Sun is on the inner edge of a spiral arm, and the latter measures suggest that the mean density within 100 parsecs of the Sun is not greater than 0.4 atoms cm\(^{-3}\) (27). At present there appears to be no method, either optical or radio, of deciding whether or not the concentration of material in a region within 5 parsecs of the Sun is about

* This point is further discussed by von Klüber (23).
40 atoms cm$^{-3}$. We note, however, that the accretion theory not only requires the Sun to be inside a cloud, but also requires this cloud to be of somewhat greater density than the average.

(e) Qualitative aspects.—The qualitative aspects must bear less weight as evidence. However, it seems difficult to reconcile the usually complex aspect of the inner corona, so remarkably dominated by the sunspot cycle, or the remarkable symmetry of the inner corona about the equator at sunspot minimum, with the accretion theory.

4. Possible modifications of the theory.—The foregoing comparison with observation shows that the theory is unacceptable in its present state. We have now to consider whether the theory can be modified or whether it has to be rejected altogether. We consider it doubtful whether any modification of the theory can explain the observed distribution of electrons around the Sun, but it is worthwhile considering whether alteration of the parameters can remove some of the other conflicts with observation. In this discussion we restrict ourselves to the type of theory which has been outlined in Section 2, namely that in which the accreted material is gas of interstellar origin whose infall also maintains the energy balance of the corona.

(a) Alteration of $v$ and $\tau_{\infty}$.—We have seen that if $v \sim 10$ km sec$^{-1}$ and $\tau_{\infty} \sim 45$ atoms cm$^{-3}$ the rate of accretion of energy by the Sun is about twenty times greater than is necessary to balance the loss of energy by the corona. This difference leads to the necessity of postulating violent convection in the lower corona. However, even without the introduction of an assumed value of the energy loss from the corona, the theory still requires convective transport of energy from the collision region, at about $1R_{\odot}$ above the photosphere, down to the lowest parts of the corona. It is important to see whether the situation can be improved by alteration of $v$ and $\tau_{\infty}$. If we suppose that accretion is a perfectly efficient process and wish to account for the electron density at any particular distance from the Sun, we notice that $v$ and $\tau_{\infty}$ cannot be chosen independently. For, suppose that the electron density at distance $r_0$ is fixed by observational requirements at $N_0$. Then, assuming symmetrical accretion for all distances less than $r_0$, the flux of energy into the Sun is fixed at

$$\frac{dE}{dt} = 2\pi m_p N_0 r_0^{1/2} (2GM)^{3/2}$$

independently of the value of $\tau_\infty$ and $v$ that may be chosen later. To obtain $\tau_\infty$ and $v$ we may now equate the flux of energy from (6) to that obtained from the accretion theory,

$$\frac{1}{2} m_p V^2 \frac{dN}{dt}.$$

Using the expression already quoted for $dN/dt$ (equation (2)) we find

$$\frac{\tau_\infty}{v^3} = \frac{N_0 V (2GM/r_0)}{4\pi GM^2}.$$  

Hence a choice of $v$ automatically leads to $\tau_\infty$ being fixed, and vice versa.

Unfortunately it is not possible to measure the velocity, with respect to the Sun, of the gas in our immediate neighbourhood. Adams (28) has made many observations of the radial velocities of distant clouds by measurements of the Doppler shifts of interstellar lines. These observations have been rediscussed by Blaauw (29) who has shown that the velocities of the clouds fit a distribution
of the form \( e^{-\eta v} \), where \( \eta \) is the mean velocity, equal to 5 km sec\(^{-1}\). As the solar motion with respect to nearby stars is of the order of 20 km sec\(^{-1}\) it seems most reasonable to take \( v \) as being of this order of magnitude rather than 10 km sec\(^{-1}\). If we take \( v \) to be 20 km sec\(^{-1}\), then \( \tau_* \) must be 360 atoms cm\(^{-3}\)—which is certainly an unreasonably high value. Only in this way can the electron density at 150\( R_\odot \) be reconciled with the accretion theory. When \( v = 10 \text{ km sec}^{-1} \) we have for the capture radius \( \sigma = 17.8 \text{ A.U.} \) and for \( v = 20 \text{ km sec}^{-1} \), \( \sigma \) is 4.5 A.U. If it is supposed that the region of symmetrical accretion is scaled down in proportion to the capture radius, then for the latter case it would be of radius 54\( R_\odot \), or 0.25 A.U. As observation can be carried to 150\( R_\odot \) we should expect to observe considerable asymmetry along the accretion axis in the zodiacal light region. But there is no sign of an accretion axis. It is equally clear from observation that accretion is not symmetrical within the sphere of radius \( x = 54R_\odot \).

If \( \tau_* \) is reduced to a local mean value of 0.5 atoms cm\(^{-3}\) from Hoyle's value of 44.8 atoms cm\(^{-3}\), we find that \( v \) must be reduced to 2.2 km sec\(^{-1}\) if the theory is still to give the required electron density at 150\( R_\odot \). But it is doubtful whether Hoyle's original theory is still applicable at such low velocities because pressure effects become important, and we should instead consider Bondi's theory (30) of symmetrical accretion which takes these effects into account. However, the observed departure from spherical symmetry is so great that this theory can have little relevance in this case.

(b) Alteration of collision cross-section in the solar atmosphere.—It has been suggested by van de Hulst (14) that \( r_* \) should be increased from 1.17\( R_\odot \) to 3\( R_\odot \). However, the above analysis (equations (6) and (7)) shows that although \( r_* \) is altered the flux of energy into the Sun and the choice of \( \tau_* \) and \( v \) are unaffected by the particular value of the collision cross-section adopted.

(c) Alteration of assumptions about symmetry.—In the accretion theory as outlined in Section 2 the simplifying assumption of spherically symmetrical accretion was made to make the analysis more tractable. If any mechanism could be found which would force the spherically accreted atoms into the plane of the ecliptic as they approach the Sun, several of the difficulties we have referred to would be removed: the high electron densities in the plane of the ecliptic could be explained without postulating a high overall rate of accretion and a large density of hydrogen in interstellar space. It is not easy to conceive such a mechanism without postulating the existence of a general interplanetary magnetic field, for which there is no supporting evidence.

5. Conclusion.—We may summarize the reasoning as follows. Three aspects of the corona concern us: its high temperature, its extension along the ecliptic, and the variation of its shape during the sunspot cycle. An acceptable theory of the corona must provide a numerical value of the temperature, quantitative data on the change of electron density with increasing distance from the Sun, and a mechanism linking the distribution of electron density near the Sun with the cycle of solar activity. In 1947 no satisfactory explanation of all these features was available. The idea that there might exist an important interaction between stars and interstellar gas was then receiving much attention and it was natural to apply the concept of accretion to the coronal problem. At first sight the accretion theory of the corona is attractive because it explains at once both the high temperature and the outer extension of the corona, although it fails to explain the marked variation with sunspot cycle. Further examination, however,
shows that there are difficulties in accepting the theory as first proposed; difficulties which have been rendered more serious by recent observations. First, the theory does not describe, even qualitatively, the electron distribution within $150R_\odot$ of the Sun. Second, to account even approximately for the electron densities at large distances from the Sun, it is necessary to postulate a high rate of accretion which leads to the supposition of powerful convection currents in the inner corona. There is strong evidence against the existence of any large convective energy transfer in this region. Third, it is shown that the theory leads to a relation between $\tau_\infty$ and $v$ which is independent of the nature of the interaction between the solar atmosphere and the accreted gas. It seems impossible to assign a reasonable value to one of these quantities without deriving an implausible value for the other.

We conclude that, whilst it is not impossible that some part of the coronal material might be of interstellar origin, it is unlikely that a theory of accretion can explain either the density of the Sun's outer atmosphere or the temperature of its inner parts.

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