(Dungey "Granted") I wish to illustrate the well known phenomena in a cylindrical shock tube.

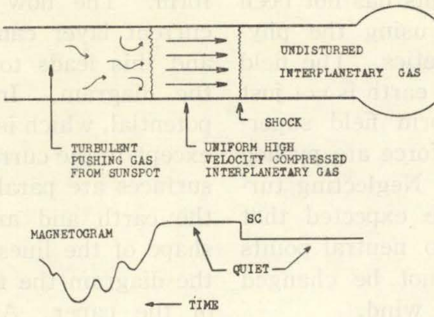

Fig. 1.

1. Is the parallel between the known shock tube phenomena and the magnetogram correct?
2. Is it also true that the pushing gas actually travels from the close vicinity of the sunspot to distances past the earth?

Dessler: 1. I believe so far the magnetograms I have shown. For other magnetic storms the situation may be more complicated.

2. Again, I believe so-your model may be taken as a simple extension of Parker's "Blast Wave" model (published in Astrophys. J., May, 1961).

Hessler, V.P.: Your presentation suggests that the pattern of the magnetic storm is determined by the structure of the solar corpuscular stream as it impinges upon the geomagnetic field. How then would one account for the similarity in form of the fine structure (10 to 20 minutes periods) of the storm which often repeats on a near 24 hour basis for two or three days?

Dessler: The phenomenon you describe may be due to a particular mode of oscillation of the magnetosphere becoming dominant for a few days. The structure in the solar wind would then be filtered by the magnetosphere; the dominant factor in determining what is seen at the earth's surface is the magnetospheric transfer function.

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INTERNATIONAL CONFERENCE ON COSMIC RAYS AND THE EARTH STORM Part II

II-1A-P2. The Interplanetary Field and Auroral Theory

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Most of the theoretical work on auroral problems omits any interplanetary magnetic field, though some time ago both Hoyle and Alfvén suggested that it plays a vital part. An attempt will be made here to predict what would happen, if there were an approximately southward interplanetary field, and it will be seen that the model appears to fit some of the observed phenomena.

In the model there is an interplanetary plasma wind, whose velocity relative to the earth is assumed to lie nearly in the ecliptic plane, and for the sake of drawing a diagram it is assumed to be coplanar with interplanetary field and the earth's dipole. The basic and awkward problem is that of the flow of plasma round the earth. This has not been solved, but will be sketched using the physical picture of hydromagnetics. The field in the neighbourhood of the earth is not just the dipole field with a uniform field superposed, because the lines of force are pushed out of shape by the wind. Neglecting turbulence, however, it may be expected that there will still be just two neutral points and that the topology will not be changed by this distortion due to the wind.

The topology of the field is important. For a dipole plus uniform field the lines of force can be computed, but the topology can be understood by considering the limiting lines in the neighbourhood of a neutral point. There are three directions such that the lines point directly towards or away from the neutral point. If two of these are towards, consider the plane containing them: in this plane all lines go into the neutral point. There is therefore a surface covered by lines of force entering this neutral point. Because of the asymmetry between lines entering and leaving a neutral point, there must be a surface covered by lines of force leaving the other neutral point. Looking now at the diagram it is seen that these surfaces separate lines of force which have both, one or no feet on the ground. The surfaces together form a cylinder extending out into space and a doughnut which intersects the earth in two closed curves at high latitudes, which will be called A-curves.

The flow in the region of a neutral point has been discussed previously (Dungey 1958)[1] in connection with the acceleration process. It was concluded that a very intense current is set up in a very thin layer containing the neutral point, so that the field reverses suddenly when this layer is crossed. The electric field in such a region is approximately uniform. The flow near but not too near a current layer can be taken as c $\boldsymbol{E}\wedge\boldsymbol{H}/H^2$, and this leads to the flow pattern shown in the diagram. In a steady state $\boldsymbol{E}$ has a potential, which is constant on a line of force, except in the current layers; the equipotential surfaces are parallel to the paper far from the earth and are distorted to take up the shape of the lines of force. In the plane of the diagram the field everywhere points out of the paper. An important feature is the reversal of the general direction of flow inside the doughnut. The electric field is connected down to the ionosphere along lines of force and produces detectable effects there. Consider lines of force leaving the earth in a circle of longitude perpendicular to the figure. The field fed to the ionosphere inside the A-curves has the same direction as the field in space: out of the paper. Lines of force from lower latitude, however, pass through the equatorial plane; the electric field in the equatorial plane is out of the paper, but following up the lines of force its direction gets turned round, so that the field in the ionosphere has a sudden reversal at the A-curves. This fits with many observations of motions in the upper ionosphere and of the electrojet, and the model does provide a precise interpretation for the auroral zones, but I will now attempt to discuss observational tests.

One general point needs consideration. The interplanetary field H_i may vary with time. Variations in strength should alter the latitude of the auroral zones though the colatitude scales only as $H_i^{1/6}$ and if the field were northward there should be no auroral zones. Variations in the direction of the interplanetary wind need only rotate the

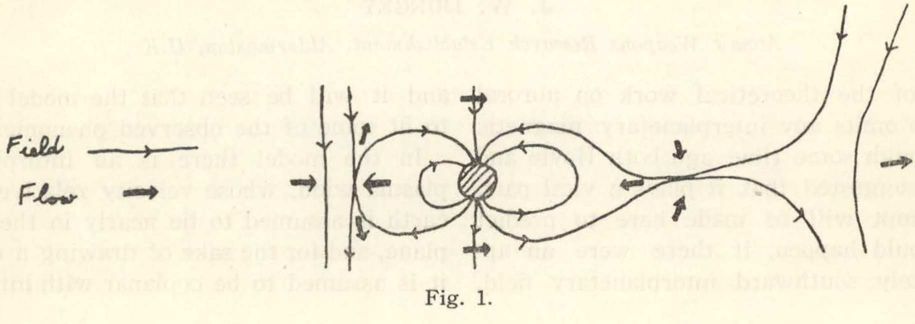

Fig. 1.

patterns about the geomagnetic axis, but variations in strength might change latitude of the auroral zones. Now it is found that the zones tend to move to lower latitudes with increasing disturbance, which is the right-way. On the other hand statistical studies of magnetic variations show the zone up sharply, implying that it is very stable. Also the auroral pattern described by Davis (1960)[2] appears to happen on a high proportion of days, without much latitude variation.

It is important therefore to look at individual days to establish just when and where the phenomena associated with the auroral zone occur. The magnetic data can be studied by rotating the horizontal vector through 90° to give an equivalent overhead current. If one is merely looking for a pattern of disturbance, it does not matter whether the disturbance is actually produced by overhead currents, the virtue of the method is that, on the plausible assumption that the vertical component of the current at the ground vanishes, the equivalent current vector is solenoidal. A study of quiet days on these lines has started at Penn State.

The model described provides an accelerating mechanism for auroral primaries. An order of magnitude for the voltages existing can be obtained from observed velocities. A modest value, 100 metres/sec., extending over 1,000 km, in a field of 0.6 gauss, gives 6 kV. Where the electric field is perpendicular to the magnetic field, however, particles can only gain or lose energy to the extent that their drift due to the non-uniformity of the magnetic field takes them across the equipotentials. The result is that particles starting with thermal energies can gain high energies only in the current sheets centred on the neutral points, but the motion of particles which already have high energies is such that their energy varies appreciably. Since the neutral points are connected by lines of force to the A-curves, a very simple explanation of aurorae is that the aurora is caused by particles coming direct from the current sheets. At the same time it is worth remarking that the critical field for a trapped particle is proportional to its energy, so that the electrostatic field could provide an effective dumping mechanism. It may also be remarked that, if a storm pushes the neutral points towards the earth and then lets them slowly out, they could feed the outer Van Allen belt.

The model shows signs of fitting the observed asymmetry between protons and electrons. For a wind from the sun, protons are attracted to the evening side of the earth, electrons to the morning side. It should be mentioned that the current sheets are expected to suffer from an instability leading to electrostatic waves which will cause a big spread in the velocities of electrons, but not protons, so that some electrons may be shot out in the "wrong" direction and also in less well-defined beams. This fits with the observation of quiet arcs, showing $H\alpha$, in the evening and peculiar diffuse forms in the morning. Also, if energies of $\sim$30 keV are assumed (the model predicts the same energies for electrons) and protons, protons will stop in the E region and electrons in the D. This agrees with the observation of sporadic E in the evening and blackout in the morning. These phenomena occur on spirals, however, whose relation to the positions of aurorae requires some clarification.

A direct test of the model should come from magnetometers on space probes. Both Pioneer I on the day side Explorer X on the night side saw many sudden reversals of the field, which in the latter case had the general direction of the sun-earth line. These observations could fit the model, if there were many current sheets, which does not seem very plausible in the hydromagnetic picture, or if there were one very corrugated current sheet, which I find plausible.

Remarks added after the conference

The results obtained on Explorer X (Heppner *et al.* *II*-5[3]) do not clearly favour any of the theoretical models. Although the test of the model presented here may well come from rocket-born observation, I would like to reemphasise the importance of analysing ground data for individual hours. A lot of statistical analysis has been presented, often the time of most frequent occurrence being studied and often leading to a spiral relationship between time of most frequent occurrence and latitude. This could be misleading, if regarded as an instantaneous picture. It is well known that the DS system moves to lower latitudes under disturbed conditions and Nagata and Fukushima (1-2-P4)[4] have shown that it moves to higher latitudes under specially quiet conditions. This could be due to a variation in strength of the solar wind. Suppose now that the direction of the solar wind also varies in direction, and that the variations in strength and direction are correlated with each other. Then the cross-over of the DS system would tend to lie on a spiral, and this could account for some of the spirals observed. In this case the spiral would not represent an instantaneous picture, because different points on the spiral would refer to different solar winds. Since Davis has already analysed aurora for five-minute intervals, it seems desirable to fill in the other phenomena for his chosen nights.

References

1) J. W. Dungey: *Cosmic Electrodynamics* (Cambridge) (1958).
2) T. N. Davis: J. Geophys. Res. **65** (1960) 3497.
3) J. P. Heppner, N. F. Ness, T. L. Skillman and C. S. Scearce: *Proceedings of Int. Conf. Cosmic Rays and the Earth Storm, Kyoto,* II-5 (1961).
4) T. Nagata: *Proceedings of Int. Conf. Cosmic Rays and the Earth Storm, Kyoto,* I-2-P4 (1961).

Discussion

Ratcliffe, J.A.: Do different signs of particles reach the earth on opposite sides of the precipitation curve?

Dungey, J.W.: The theory and the SD system shows a positive potential on the morning side and negative on the evening side, implying at least a tendency for protons in the evening. I thought such a tendency appeared in the observations, but Dr. Hines tells me *Hα* is symmetrical between morning and evening.

Lüst, R.: 1. You stated at the beginning that you have not taken into account the rotation of the earth. But would you not expect that the rotation would change the picture considerably, especially since one must disconnect the field line with the interplanetay space?

2. Could you say at what distances from the earth the neutral points are located?

Dungey: The rotation of the earth is important, but not enough to swamp the flow I discussed. The position of the neutral points will have to be measured.

Parker, E.N.: Would you expect any significant auroral changes when the sun reverses its field?

Dungey: If the interplanetary field reversed, the auroral zone would disappear. We are now exploring outwards with rockets rather than inwards from speculations.

Nagata, T.: Could you suggest any possibility to explain my sunlit polar cap geomagnetic perturbation with your picture?

Dungey: Most theories relate high latitude perturbations to the interplanetary plasma. My point is that if the auroral zone has always the same latitude except during storms, this implies that the interplanetary conditions vary only during storms, which I find implausible. I am therefore pleased to see the auroral zone at higher latitude on exceptionally quiet days.

Singer, S.F.: You argue for a sharp velocity distribution of auroral particles against a statistical acceleration mechanism. However, the analysis of auroral luminosity vs altitude gives a $1/v^4$ velocity distribution (Chamberlain). Could you comment?

Dungey: I did not mean a sharp distribution in energy. The point is that one must get aurora in an arc and *not* elsewhere.

Kellogg, P.J.: I would like to argue against too hasty a conclusion that the interplanetary field is perpendicular to the ecliptic plane. It is true that this is the simplest conclusion from the Pioneer *V* magnetometer data. But Dr. McCracken has given us the strongest reasons for believing that the field in the galactic plane and points about 55° from the sun. His observations of the direction of arrival of solar protons, as well as other observations of the direction of arrival of solar protons, as well as other observations of prompt arrival of solar protons after a flare, argue strongly against a field perpendicular to the galactic plane. I believe that the Pioneer *V* observations can be made consistent with McCracken's field. The Pioneer *V* data was digitalized before transmission and the most common value of 2.5 γ fill into a rather wide window. Further, the most important data toward the end of transmission when the spin axis of the magnetometer pointed 270° west of the sun, is obscured by a magnetic storm. I think that, with a little allowance for errors and fluctuations, a curve consistent with McCracken's field can be drawn through the observed points.

Sonett, C. P.: *Comment on Kellogg's remarks.* The window width on the Pioneer *V* magnetometer experiment were nonlinear. In the region of 2.5 γ the width were $<10\%$ wide. This can be seen in Fig. 1 of paper II-5-1. It is not possible, from this experiment to rule out a solar wind field spiralled at an angle to a solar radius of more than about 80°. The data appear to be in conflict with a radial component 20.5γ during the approximately 50% of the time during the two months of observation when the field was apparently quiet. Additional comments are available in Coleman, P. J. Jr., Leverett Davis, Jr., and C. P. Sonett; Phys. Rev. Lett. July (1960) and Same authors J. Geophys. Res. July (1961).