Comments on the Paper 'The Internal Structure of the Geomagnetic Neutral Sheet' by K. Schindler and N. F. Ness

CHRISTOPHER T. RUSSELL

Institute of Geophysics and Planetary Physics
University of California, Los Angeles, California 90024

Recently Schindler and Ness [1972] have postulated that the current sheet in the geomagnetic tail contains many X-type neutral points separated by regions of northward magnetic field. In this model X-type neutral points exist on closed field lines. The apparent need for such a model arose from an analysis of Explorer 34 magnetometer data obtained near the center of the tail 30 $R_E$ behind the earth. By examining the distribution of field values in a space defined by $B_z$ and $B_e$ in solar magnetospheric coordinates, Schindler and Ness demonstrated that the observations could not be explained with a one-dimensional magnetic field structure in which the field normal to the current sheet ($B_z$) remained constant while the field parallel to the current sheet ($B_e$) varied. Schindler and Ness showed that these observations are, however, consistent with the multiple neutral point hypothesis. They carefully point out that this explanation is not unique, but they do not offer any viable alternative interpretations of their data. It is the purpose of this note to emphasize that there are several alternative interpretations of the distribution of field values observed by Explorer 34, one of which, in fact, does not require the presence of neutral points.

Models without neutral points. The region of the magnetosphere most similar to the tail current sheet is the magnetopause. The change of the magnetic field in the plane of the boundary during passages through the magnetopause has been extensively studied [Sonnerup and Cahill, 1967, 1968; Aubry et al., 1971; Sonnerup, 1971]. The field is observed to change one dimensionally and two dimensionally. A one-dimensional change consists of the field shrinking and then growing along one direction; a two-dimensional change consists of the field rotating about the direction normal to the boundary. The two-dimensional change is usually observed when there is a large component of the field normal to the magnetopause, whereas the one-dimensional change usually has a small normal component. Hybrid situations, of course, occur in which there is some linear shrinkage and some rotation.

A priori, the neutral sheet in the region of 30 $R_E$ should most closely resemble the magnetopause whose internal structure is rotational. The bounding fields are antiparallel and there is a moderately large ($\sim 2 \gamma$) normal component. On the other hand, we know that the field magnitude decreases significantly in the current sheet. Thus the main part of the field reversal must occur via shrinkage-expansion rather than rotation. Such hybrid shrinking-rotating structures are not uncommon at the magnetopause [cf. Aubry et al., 1971, Figure 13; Sonnerup, 1971, Figure 8]. Therefore it is probable that they exist at the neutral sheet also.

The upper panel of Figure 1 shows such a hypothetical variation of the magnetic field projected into the plane of the current sheet during a satellite traversal through the current sheet. Here the A axis is in the sheet pointing toward the earth and the S axis is in the sheet perpendicular to the A axis. As the satellite passes through the sheet from the south lobe to the north lobe, the field first shrinks, then rotates through the low field region, and then stretches until it reaches its original magnitude in the north lobe pointing in a direction antiparallel to the initial direction.

Since the Schindler and Ness data are the only available high resolution data at the neutral sheet at these radial distances, and since they did not analyze the three-dimensional structure of the crossings, such a structure

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must remain conjecture. However, an examination of neutral sheet crossings in this region with 5-min average data [Speiser and Ness, 1967] reveals that, at least on occasion, $B_x$ can be essentially constant and moderately large ($\sim 3\gamma$) through the current sheet. This behavior is sketched in the lower panel of Figure 1. In this case, the field is simultaneously rotating and decreasing or increasing in magnitude throughout the crossing. The low field region is not a well-defined separate entity here but can be defined (e.g., $|B^4| \leq |B^s|$).

Schindler and Ness have discussed the situation in the high field region in which the field is predominantly in the A-N plane ($N$ is the direction normal to the sheet). Here twisting of the current sheet about the S direction will cause fluctuations in the solar magnetospheric Z component. (The solar magnetospheric Z direction is assumed by Schindler and Ness to be perpendicular to the current sheet on the average.) In the low field region a flapping about the A direction will cause similar fluctuations in the $B_z$ component. This is illustrated in Figure 2, which applies to either the hypothetical (upper panel of Figure 1) or the observational (lower panel) variation. The component normal to the sheet $B^s$ is projected onto the Z axis as $B^s \cos \theta$, and the component $B^s$ in the sheet normal to the A axis is projected as $B^s \sin \theta$. At first glance one might expect random twisting about the solar direction to increase the variability of $B_z$ in the low field region. However, Schindler and Ness [1972] report merely a decrease in $B_z$ here. On the basis of the present suggestion, this could occur for two reasons.

The first possible explanation is that fluctuations during the measurement interval cause a reduction in the average amplitude. For example, consider a low field region with $1-\gamma B_z$ and $1-\gamma B_x$ components. If the tail twisted $45^\circ$ one way, the measured $B_z$ component would be $0\gamma$, and, if the tail twisted $45^\circ$ the other way, the measured $B_z$ component would be $1.4\gamma$. If an average of these two values is taken, the $B_z$ component is $0.7\gamma$ rather than 1.

The second possible explanation is that there was a 'permanent' twist to the tail current sheet during the neutral sheet crossings of Explorer 34. This 'permanent' twist could occur in one local region or over one time interval. Local twists of the solar magnetospheric equator are expected [Russell and Brody, 1967]. However, the angle of twist about the solar direction required for this effect to explain the disappearance of the Z component in the current sheet is moderately large. For example, if $B^s$ is $2\gamma$, as measured by Schindler and Ness [1972], and $B^s$ is $3\gamma$, as measured by Speiser and Ness [1967], then the angle $\theta$ in Figure 2 is $34^\circ$.  

Fig. 2. The contribution of $B^s$ (the component normal to the current sheet) and $B^w$ (the component in the plane of the current sheet but perpendicular to the tail axis) to the solar magnetospheric Z component of the magnetic field when there is a twist of the current sheet about the tail axis.
Such a twist is not expected to be produced solely by the warping of the neutral sheet as treated in the formula of Russell and Brody. Most of the Explorer 34 data were obtained near a Y solar magnetospheric position of $-5 R_E$. At this position at the time of year of the Explorer 34 observations, the Russell-Brody model predicts a twist varying only from 0 to $10^\circ$.

On the other hand, a permanent twist of the whole neutral sheet over the period of the Explorer observations could be caused by the interplanetary magnetic field [Russell, 1972]. We note that most of the Explorer 34 data were obtained within one 39-hour interval, a period short compared to the duration of a typical solar sector [Wilcox and Ness, 1965]. Thus, if the interplanetary field is effective in twisting the tail, one need not invoke a neutral point crossing to explain the Explorer 34 data.

Models with neutral points. While one of the alternative explanations of the Explorer 34 data involves no neutral point, there are alternatives to the Schindler-Ness model that do involve neutral points. Since $B_z$ is predominantly northward at Explorer 34, if a single neutral point exists, it must on the average be farther from the earth than Explorer 34. Also, if a single oscillating neutral point were to have caused the various neutral sheet encounters at an average spacing of 100 sec, then velocity considerations require the average position of the neutral point to have been within several earth radii of Explorer 34. Under the same assumptions, similar observations at 60 $R_E$ with Explorer 35 on a different day require the neutral point to have been within several earth radii and tailward of Explorer 35 during the observation. Schindler and Ness consider this to be an unlikely coincidence. However, Nishida and Nagayama [1973] have shown that, though the neutral point is usually beyond the moon, it can exist closer to the earth than 30 $R_E$ for periods of the order of a half hour at the onset of substorm expansion phases. In fact, at the time of the only example of high-resolution neutral sheet crossing that Schindler and Ness show (0410-0445 UT, February 26, 1968) there was a small negative bay in the $H$ component magnetograms from Narssarsuaq, Greenland, near local midnight. Furthermore, the temporary increase of the field from 0400 to 0412 to near expected tail lobe values suggests plasma sheet thinning, which is expected before the formation of a near-earth neutral point [cf. Russell, 1972]. Hence it appears that at least this particular event occurred during a time of temporal changes in the tail, and it is possible that this temporal change was the formation or motion of a neutral point closer to the earth. Thus we cannot rule out a moving single neutral point at this time.

Finally we note that, while Schindler and Ness have suggested that several neutral points exist in space, an alternative to this model, which is physically different, is that multiple neutral points exist in the time domain. In the latter model neutral points would be continually forming and being lost or destroyed. In the former model the average northward field at Explorer 34 and 35 is a spatial average; and in the latter model it is a temporal average.

Summary and conclusions. In summary, it is possible to interpret the tail magnetic field observations of Schindler and Ness without requiring neutral point encounters. On the other hand, if it is assumed that the observed field variations were due to neutral point encounters, there may be a single oscillating neutral point and there may be multiple neutral points in time or in space. We conclude that the internal structure of the neutral sheet must be studied further. Much more work is needed in analyzing the three-dimensional current pattern at the neutral sheet and in measuring the motions of these patterns. The latter measurement will require a multiple satellite experiment.

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References


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