1. **Introduction:** The interplanetary magnetic field contains regions of alternate polarity. Reconnection of lines of force and magnetic field annihilation can take place across the surface, or neutral sheet, separating these regions, if the parameters of the ambient plasma have values such that these phenomena are possible. It is not clear at the moment which are the controlling parameters and when these phenomena are allowed. The reconnection of magnetic lines of force has been studied theoretically by Petschek (1964), Petschek and Thorne (1967), Sonnerup (1970), Sonnerup (1972), Yeh and Axford (1970). Experimental work on collisional plasmas has been done in the laboratory (cf. Bratenahl and Yeates, 1970), and observational studies in space have been carried out by Burlaga and Scudder (1973) and Unti et al. (1972) for annihilation of magnetic field in D-sheets, and by Schindler and Ness (1971) for the geomagnetic tail. From these studies it appears that two important parameters are: the plasma resistivity $\sigma$ that appears to have anomalous values compared to those obtained from Spitzer's relation (cf. Burlaga and Scudder, 1973; Spitzer (1962);
and the ratio, plasma pressure to magnetic pressure, \( B \), (cf. Sonnerup, 1972). In this paper we will present a preliminary study of two sets of data taken from HEOS-1 and OGO-5 in the solar wind, that shows the internal structure of two neutral sheets and their two dimensional structure.

2. The tearing mode instability in the neutral sheet of Day 311, 1969: On Day 311, 1969 HEOS-1 observed a sector boundary between 0220 and 0245. The magnetic field intensity \( B \) and direction \( \theta \) and \( \psi \) are shown in Fig. 1. Complicated structures are observed in connection with the sector boundary, such as an increase in \( B \) from 3 to 12\( \gamma \) at 0150 UT, 30 minutes before the depression in \( B \), coincident with the neutral sheet. The high magnetic field values last until 1200 UT. The depression in the magnetic field intensity appears to be unusually large if compared with most D-sheets observed by Burlaga and Ness. The minimum value of \( B \) also appears to be unusually low not only in the low time resolution measurements but also in the high time resolution data available for the last 10 minutes of the hole itself (see also Fig. 3). The plasma data through the field depression are shown in Fig. 2. It should be noted that \( B \) is between 11 and 12\( \gamma \) on both sides of the neutral sheet, while the minimum value, observed at 0241 - 0243 UT is of the order of 1\( \gamma \) or less. The number density \( N \) ranges between 1 and 3 protons/cm\(^3\) before the neutral sheet and between 5 and 6 protons/cm\(^3\) after it. Within the
neutral sheet densities as high as 18 p/cm$^3$ are observed. The proton most probable thermal speed is also low (20 km/sec) on both sides of the sheet, while within the sheet reaches values 4 times higher (≈80 km/sec). It should be noted that the total energy density appears to be roughly constant through the first wall of the sheet, but increases very much when the minimum magnetic field intensity is observed, so that a large decrease of $E$ is observed through the second wall of the neutral sheet. The ratio of plasma pressure to magnetic pressure computed assuming $T_e=2 T_p$ and $N_e=N_p$ is shown in the top panel of Fig. 2. While $B$ is lower than $10^{-1}$ on both sides of the neutral sheet, within the depression it increases up to almost $10^2$, a factor of 100 higher! Even if the hypothesis that $T_e=2 T_p$ may not be valid within the sheet, the plasma pressure, of the observed protons, exceeds that of the magnetic field by over an order of magnitude. If a low value of $B$ close to the sheet is a necessary condition for fast magnetic field reconnection and annihilation (cf. Sonnerup, 1972), the observed low value of $B$ on the two sides of the discontinuity may explain the large dimension of the neutral sheet itself. The internal structure of the neutral sheet is shown in Fig. 3 for the last part of the valley observed for the magnetic field intensity with high time resolution magnetic field data. The magnetic field appears to be rather noisy both in magnitude and direction. At 0241 UT $B$ appears to be low as 0.5$\gamma$. 
At 0244:30 UT B jumps from 2γ to 11γ. The magnetic field direction $\psi$ within the ecliptic plane shows some very interesting features: while at 0236 UT $\psi = 240^\circ$, at 0245 UT $\psi = 120^\circ$. The decrease of $\psi$ from $240^\circ$ to $120^\circ$ is not smooth. Superimposed to a continuous trend peaks appear to be present of larger and larger maximum values. The first maximum is at $260^\circ$ (0237:30 UT); then $295^\circ$ (0238:20 UT); then $310^\circ$ (0240:40 UT); then $330^\circ$ (0241:30 UT). Other maximum at 0239:30 and 0240:30 UT may have existed, but are destroyed by strong noise. We believe that this way of changing from one direction to another one of opposite polarity, observed within the region of minimum magnetic field intensity, indicates the presence of closed loops. The neutral sheet appears to be crossed at a large angle to the normal of the surface of discontinuity, causing many loops to be observed. The presence of loops implies that the tearing mode instability is active in the neutral sheet (cf. Schindler, 1971). Further information is available from OGO-5, in the magnetosheath at this time. The neutral sheet was clearly located in the magnetometer data. No correlation is immediately possible between the two satellites because of possible modification of the instability, by the interaction with the bow shock. The search coil data, however, shows noise up to 47 Hz in the neutral sheet itself, and this noise may be independent of the bow shock. We may estimate the neutral sheet thickness from the bulk speed of the plasma.
(250 - 270 km/sec within the neutral sheet) and the time length of the pulses is \( \approx 20 \text{ seconds} \). A thickness of 5000 - 5400 km is obtained in this way.

A thickness of \( 10^4 \) km for the neutral sheet was predicted at 1 AU by Pneuman (1972), while Schindler (1972) computed that depending on the actual cause of the tearing mode, the thickness of the neutral sheet could have been, at 1 AU, of the order of 500 km (resistive tearing), 2000 km (collision free tearing) and 40,000 km (collective-resistive with \( \text{eff} = 10^3 \omega \rho \)). The value obtained from our observations appears to be close to the value predicted from the collision free tearing. We note that oscillation within neutral sheets of the magnetic field direction such that loop structures can be inferred, have been observed many other times and will be discussed in a future paper.

3. Interchange instability at the neutral sheet of Day 64, 1969:

On Day 64, 1969 HEOS-1 observed with high time resolution three neutral sheets within three minutes. Magnetic field data are shown in Fig. 4. Until 1135 UT a steady magnetic field with \( \Theta = -55^0, \Psi = 330^0 \) is observed; then after a few seconds with data missing, the satellite crossed the first neutral sheet and found a \( B = 11 \gamma, \Theta = -50^0, \Psi = 40^0 \), within the sheet, a decrease of \( \Psi \) and an increase of \( \Theta \) was observed. At 1138 UT a second neutral sheet was observed, followed 50 seconds later by the last one. The magnetic field between second and third sheet was different and showed fluctuations in \( \Psi \) that, although
on a shorter time scale, resemble those observed on Day 311, 1969 within the neutral sheet. The oscillations are of increasing amplitude until the satellite observed the minimum value of B and quickly passed through to the other side of the sheet (see Fig. 5).

The plasma data for this period are shown in Fig. 6 by three energy spectra. Due to the different time resolution, the spectrum shown in the middle of Fig. 6 covers a period longer than the time interval between the first and third neutral sheet. As a result, while before and after the three sheets we observe a second peak at low energies (cf. Feldman et al., 1973), across the sheets, the second peak disappears and a larger thermal speed is obtained. It is possible that this is due to fluctuations of the plasma that the instrument is not able to resolve. Low frequency electromagnetic fluctuation data and OGO-5 are compared with HEO-1 observations in Fig. 7. The observations appear to be very different. In coincidence with the first sheet observed by HEO-1, OGO-5 starts to observe a large magnetic field decrease that lasts 2 minutes and ends when HEO-1 observes the second sheet. It is possible that a small and short decrease in B observed by OGO-5 40 seconds earlier can be interpreted as a not-close crossing of the sheet. This interpretation is supported by a change in direction similar to that observed at the large sheet. Evidence for another quasi-crossing of a neutral sheet
is given by a magnetic field directional change observed by OGO-5 at 1131:50 UT.

Note the presence of electromagnetic noise up to 50 Hz in the region of minimum value of B. In Fig. 8 we suggest a possible interpretation of the observations. It appears natural to assume that the three sheets crossed by HEOS-1 are connected to the same phenomenon. Under this assumption our task is to interpret the OGO-5 observations in some way. A picture of the sheet shape when the large B depression reached OGO-5 has been constructed in Fig. 8 using the observed time delays and a solar wind speed of 400 km/sec; we have also taken into account the fact that for many minutes before and after the sheet crossings shown, no other sheet crossings were observed. The picture shows large amplitude oscillations of the neutral sheet with amplitude of 15-20 $R_E$. It should be noted that the total pressures observed in plasma 1 and in plasma 2 are not equal, but plasma 2 has a pressure 1.77 times higher than plasma 1. The large oscillations, in space, of the neutral sheet may therefore, be due to this unbalance of the total pressure, that generates an interchange instability.

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**Fig. 1** - HEOS-1 magnetic field data for the sector boundary observed on Day 311, 1969 0240 UT

**Fig. 2** - Magnetic field intensity, proton number density and thermal speed, total energy density and $\beta$ for the neutral sheet observed on Day 311, 1969 0240 UT
Fig. 3 - High time resolution magnetic field data for the last part of the neutral sheet observed on Day 311, 1969. Note the extremely low values of B occasionally observed (0.5\gamma) and the pulses in the values of while the longitude changes from 2400 to 1200.
Fig. 4 - High time resolution magnetic field HEOS-1 data for the three neutral sheets observed on Day 64, 1969.

Fig. 5 - Oscillations of magnetic field direction observed by HEOS-1 in between the second and third neutral sheet.
Fig. 6 - Positive ions energy spectra observed by HEO-1 across the three neutral sheets of Day 64, 1969.

Fig. 7 - Magnetic field intensity observed by HEO-1 (bottom), OGO-5 and electromagnetic noise data (10, 22, 47 Hz) observed by OGO-5 for the neutral sheets crossings of Day 64, 1969.
Fig. 8 - Projection of HEO5-1 and OGO-5 positions in the XY and XZ plane. The average position of bow shock and magnetopause is also indicated. Thick segments indicate positions of the neutral sheets as deduced from solar wind speed (400 km/sec) and time intervals between observations. Small arrows indicate magnetic field directions observed by HEO5-1 in the ecliptic plane. Dashed lines indicate a neutral sheet possible configuration that on average follows the 45° Archimedean spiral.