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# ANOMALOUSLY HIGH POTENTIALS OBSERVED ON ISEE*

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Data from the two electric field experiments and from the plasma composition experiment on ISEE-1 show that the spacecraft charged to close to -70 V in sunlight at about 0700 UT on March 17, 1978. Data from the electron spectrometer experiment show that there was a potential barrier of some -10 to -20 V about the spacecraft during this event. The potential barrier was effective in turning back emitted photoelectrons to the spacecraft. Potential barriers can be formed because of differential charging on the spacecraft or because of the presence of space charge. The stringent electrostatic cleanliness specifications imposed on ISEE make the presence of differential charging unlikely, if these precautions were effective. Modeling of this event is required to determine if the barrier was produced by the presence of space charge.

## INTRODUCTION

The International Sun Earth Explorer (ISEE) project involves three spacecraft which were designed to study the magnetospheric plasma under the auspices of the International Magnetospheric Study program. ISEE-1 and ISEE-2 were launched on October 22, 1977, into almost identical orbits but with a variable separation distance in order to be able to separate temporal and spatial variations of the environment. Their apogee was at 23 earth radii, and their period was approximately 57 h. ISEE-3 was launched into a "halo orbit" about the libration point at about 240 earth radii towards the sun from the earth. Further information on the ISEE mission can be found in References 1 through 3.

The ISEE spacecraft were built according to a set of electrostatic cleanliness specifications which were intended to make the exteriors of the spacecraft be equipotential surfaces and to prevent the buildup of asymmetric potentials which could interfere with low energy particle and electric field measurements. The specifications required that no exposed spacecraft component (with some exceptions) charge to potentials in excess of 1 volt with respect to the spacecraft potential. This requirement demanded that all spacecraft components that were exposed to the plasma environment be "sufficiently conducting," and be connected to the spacecraft ground through low impedance paths. These specifications which were also used in the construction of the GEOS spacecraft, appear to have been relatively effective; the most negative potential reached by GEOS 2 was -1500 volts in eclipse which is

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much less than potentials reached by other magnetospheric spacecraft such as ATS-5, ATS-6 and SCATHA (References 4 through 6).

In spite of these electrostatic cleanliness requirements, there have been indications of significant charging events on ISEE-1, with the spacecraft going at times to a negative potential on the order of -100 volts in sunlight. These indications came from ion data obtained by the plasma composition experiment (Ref. 7) which showed that low energy (thermal) ions had been accelerated to kinetic energies on the order of 100 eV before they were detected by the instrument. It is important to understand such charging events, if they are indeed real, in order to be able to evaluate the effectiveness of the electrostatic cleanliness specifications. For example, the charging of electrostatically "dirty" spacecraft such as ATS-5, ATS-6 and SCATHA has been shown to be very dependent on differential charging effects (Ref. 8 and 9). Differential charging on a spacecraft can produce a potential barrier which prevents low energy photoelectrons from escaping, and can thus lead to much larger negative potentials in sunlight than would otherwise be expected. The purpose of this paper is to examine in detail such a sunlight charging event on ISEE-1.

## DATA THAT INDICATE CHARGING

Several experiments on ISEE-1 are capable of giving information on the potential of the spacecraft. In this section we present evidence from the two electric field experiments and from the plasma composition experiment which indicate that between 0600 and 0800 UT on March 17, 1978 (Day 76), the ISEE-1 spacecraft charged to about -70 volts in sunlight. At that time the vehicle was near synchronous orbit, at 7.7 earth radii, and at 0300 local time. In addition, we present data from a synchronous altitude spacecraft, ATS-5, on the same date but at about 0400 UT and at midnight local time, which show that ATS-5 charged to about -6 kV in eclipse. Thus the plasma environment during this period of time was sufficiently hot to provide significant charging.

The spherical double probe electric field experiment on ISEE-1 (Ref. 10) measures the potential difference between the probes, which are two 4 cm radius spheres at the ends of wire booms separated by 73.5 m in the spin plane of the spacecraft. In addition, the experiment monitors the potential difference between each of the probes and the spacecraft. The potential of the spheres with respect to the plasma is adjusted to be near zero by introducing bias currents to the spheres based on current/voltage sweeps which are made during a quarter-second interval every 128 sec.

Figure 1 shows the quantity V2S which is the potential difference between sphere #2 and the spacecraft during the interval from 0500 to 0800 UT on March 17, 1978. The spacecraft potential with respect to the sphere (which was near ambient plasma potential) is the negative of V2S. The figure shows that the spacecraft was near zero volts at 0600 and that it gradually charged to a more negative potential, going off-scale at -50 volts at about 0715 UT. The potential came back on scale briefly at 0745. During the period from 0700 to 0800 the vehicle potential was close to or more negative than -50 volts. Since the sphere bias current is negative at this time (i.e., electrons are being pushed onto the sphere), the fact that the spacecraft is more negative than the sphere implies that the sphere and the spacecraft are responding differently to the environment. For example, there may be more secondary electrons emitted from the sphere, or there may be potential barrier effects around the spacecraft that are not around the sphere.

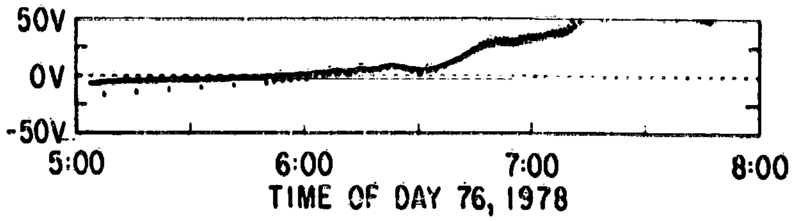

Figure 1. Probe data from Mozer's electric field experiment showing the probe-to-spacecraft potential (V2S) from 0500 to 0800 UT on March 17, 1978.

Figure 2 shows similar data from the Goddard electric field experiment on ISEE-1 (Ref. 11). The active probes in this experiment are 36 m uninsulated tip sections of two wires independently deployed to lengths of 106.7 m. This gives an effective baseline between the two active elements of 179 m. The figure shows the potential difference between one of these elements and the spacecraft during two periods of time: at 0600 and at 0645 UT. The potentials of the active elements in this experiment are floating with respect to the ambient plasma. That is, the potential of the elements is determined by a current balance between collected plasma ions and electrons and emitted secondary electrons and photoelectrons. The floating potential is modulated by the spin of the spacecraft. The potential is most positive when the wire elements are perpendicular to the direction of the sun since this is the orientation where the photoemission current is a maximum.

The floating potential of the active wire elements with respect to the local plasma is not directly measured in this experiment, but it is expected to be on the order of a few volts positive when the wires are perpendicular to the sun direction. The two spherical probes in the other electric field experiment floated at approximately +5 V during this period of time, as determined from current/voltage sweeps when the bias current was

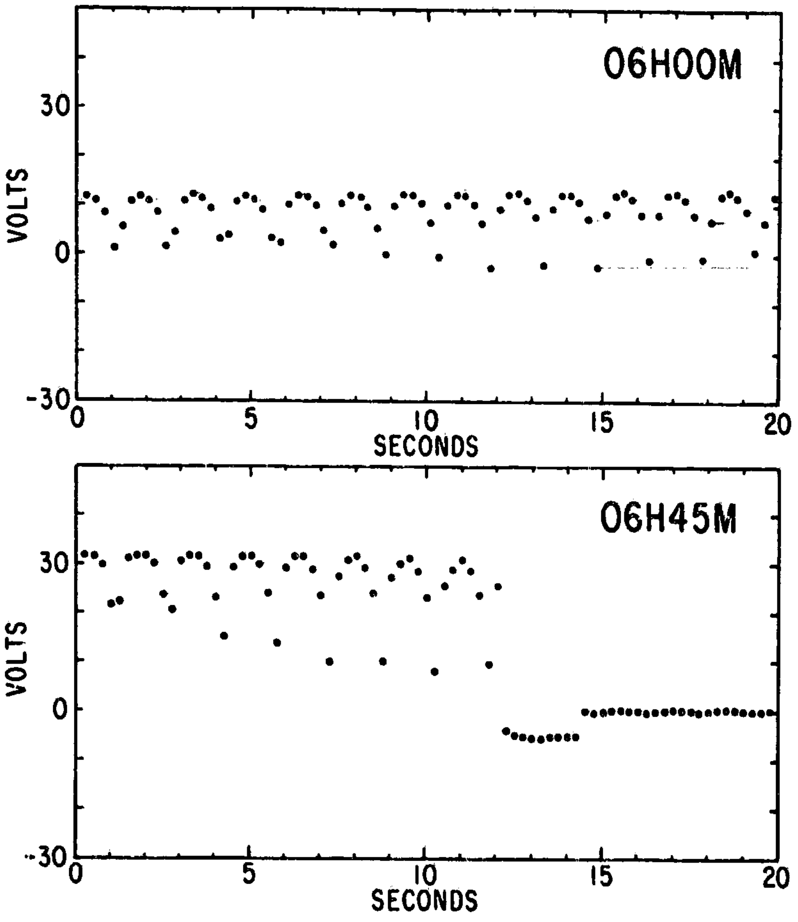

Figure 2. Probe data from Heppner's electric field experiment showing the probe-to-spacecraft potential at 0600 and 0645 UT on March 17, 1978.

zero. If the wire element is also floating at about +5 volts during this time, then the spacecraft potential has changed from near zero to about −25 V between 0600 and 0645. These values are in reasonable agreement with the data shown in Figure 1.

The plasma composition experiment is described in Ref. 7. It consists of two identical mass spectrometers which can be operated independently. The ions enter a collimator and then go through a three-grid retarding potential analyzer (RPA). The retarding grid is programmable between 60 mV and 100 V in 32 steps with approximately equal logarithmic intervals. After passing through the third grid, the ions are accelerated through a potential difference of approximately −2950 V before they pass through a cylindrical electrostatic analyzer. Due to the pre-acceleration, the lowest energy step of the electrostatic analyzer passes all ions with external energies between zero (i.e., those cold ions which can reach the spacecraft) and approximately 100 eV.

Figure 3 shows results from the plasma composition experiment between 0600 and 0800 UT on March 17, 1978. The four panels show ion counts during the four half-hour intervals, where the data has been accumulated as a function of spacecraft spin angle and RPA retarding potential. The count rate is indicated by the gray scale, with dark signifying high count rates, and light signifying low count rates. The retarding potential at which the count rates are sharply reduced is a measure of the (negative) spacecraft potential. In this mode of operation, the instrument is passing all species of ions, but it is known from the other modes of operation that the ions are predominantly hydrogen but with a significant oxygen component. It can be seen that this cut-off potential increases during this period of time from about 10 V at the beginning to somewhat under 100 V at the end.

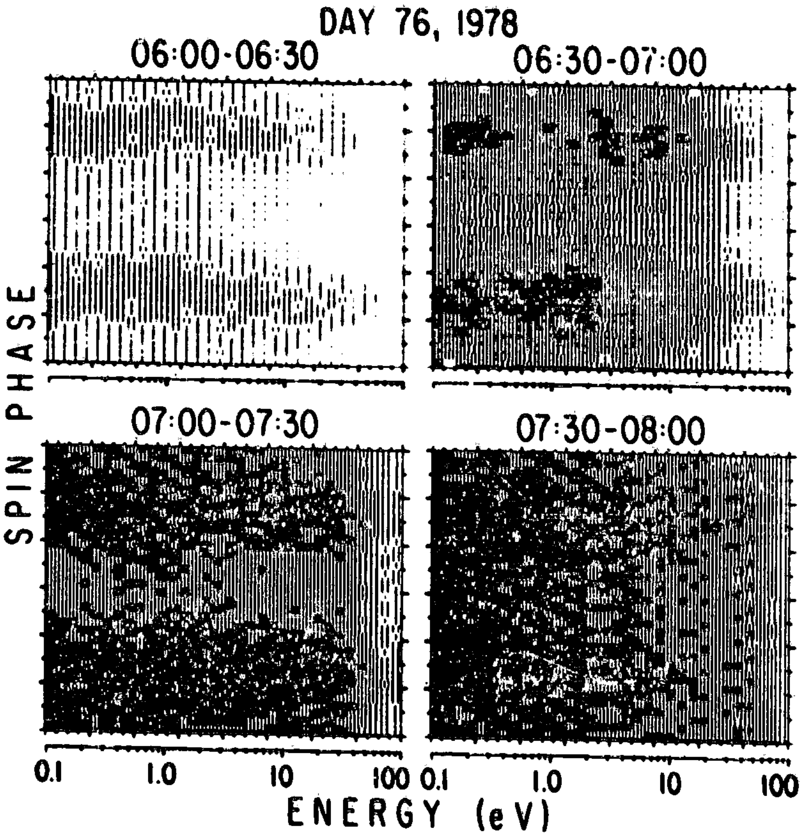

Figure 3. Ion data from the plasma composition experiment from 0600 to 0800 UT on March 17, 1978. Dark indicates high ion counting rates and light indicates low rates. The energy at which the counting rate decreases abruptly is an indication of the spacecraft potential.

Individual RPA scans were examined during part of this period of time, and the spacecraft potential was estimated for scans when the experiment was most nearly looking at ions coming in the ram direction. Individual scans were obtained approximately every three minutes, although there were some gaps in the data. The results are shown in Figure 4. Again, the data show that the potential of the spacecraft increased in the negative direction from near -5 V at about 0630 UT to a value more negative than -60 V after 0710 UT.

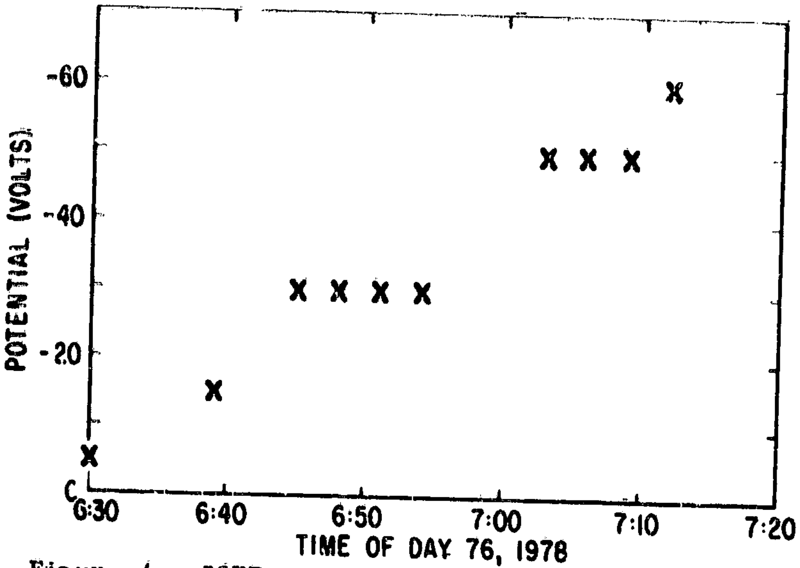

Figure 4. ISEE spacecraft potentials on March 17, 1978, inferred from the plasma composition experiment.

Figure 5 shows a spectrogram from the UCSD particle detector on the ATS-5 satellite between 0410 and 0510 UT on the same day. Data is only available during the time when the spacecraft was entering and within the earth's shadow. This was a period when special operations of the ATS-5 ion engine and neutralizer were being carried out to test the capability of these devices to discharge the spacecraft (Ref. 12). The spacecraft entered eclipse at 0411; the neutralizer was turned on at 0418 and off at 0433. The neutralizer consisted merely of a heated filament which could emit electrons independently of operation of the ion engine. During the neutralizer operation, the spacecraft potential was held to about -2 kV but when it was turned off the potential went to about -6 kV. The ion spectrum during this period of time as measured by the UCSD detector is in good agreement with the ion spectrum obtained by the LEPEDEA experiment (Ref.13) on ISEE-1 at 0700 UT. Thus it appears that the plasma near geosynchronous

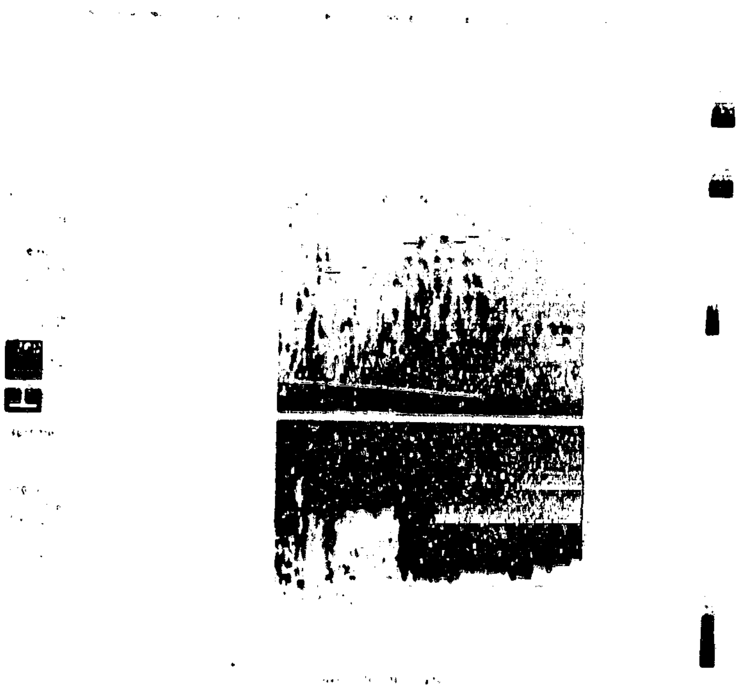

Figure 5. A spectrogram from the UCSD particle detector on the ATS-5 spacecraft showing charging to about -6 kV in eclipse on March 17, 1978. The dark regions indicate low count rates.

orbit during the morning of March 17, 1978, was sufficiently hot to charge "dirty" spacecraft such as ATS-5 to several kilovolts negative in shadow, and "clean" spacecraft such as ISEE-1 to approximately -100 V in sunlight.

## EVIDENCE FOR A POTENTIAL BARRIER

Figures 6 and 7 show electron data from the Electron Spectrometer experiment on ISEE-1 (Ref. 14). The electron distribution function on a logarithmic scale is shown against electron energy at 0600 UT (Fig. 6) and at 0700 UT (Fig. 7). At 0600 the spacecraft potential was near zero whereas at 0700 the potential was on the order of -40 V, as we showed in Section 2 (See Figure 4). At low energies, both Figures 6 and 7 show a steepening of the electron spectrum characteristic of photoelectrons and/or secondary electrons.

The straight line in Figure 6 which goes through the lower energy electrons indicates that these electrons are characterized by a density of about 20 cm$^{-3}$ and a temperature near 2 eV. These values are very reasonable for photoelectrons emitted from typical spacecraft surfaces at the earth's distance from the sun. The actual value of the photoelectron density would of course depend on the material and on the orientation of the emitting surface with respect to the solar direction. The fact that photoelectrons with energies as high as 20 eV are seen returning to the spacecraft indicates that there must be a significant electric field which turns back the emitted photoelectrons. In other words, there must be a potential barrier around the spacecraft. This behavior of the electron spectrum was seen at all orientations of the spacecraft during its spin, although the magnitude of the inferred photoelectron density was somewhat modulated by the spin.

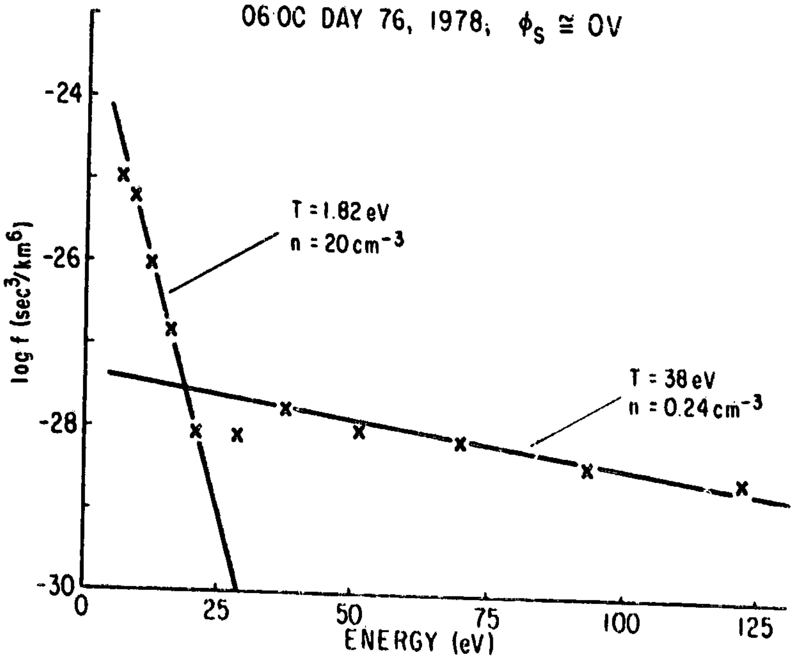

Figure 6. Electron distribution function from the ISEE electron spectrometer at 0600 UT on March 17, 1978.

The behavior of the electron spectrum in Figure 7 is similar to that in Figure 6. The low energy part of the spectrum is fitted well by a Maxwellian distribution with a temperature of 3.4 eV and a density of about 9 $cm^{-3}$ if these low energy electrons are photoelectrons coming from the spacecraft. If these low energy electrons were ambient plasma electrons reaching a negatively charged spacecraft at -40 V, they would have to have a density of almost $10^6$ $cm^{-3}$ in the undisturbed plasma. This is completely unreasonable for the plasma at this location near geosynchronous orbit in the earth's magnetosphere. We conclude, therefore, that there must still be a potential barrier around the spacecraft at 0700 UT in spite of the negative spacecraft potential.

The higher energy parts of the distributions in both Figures 6 and 7 give reasonable values for the plasma electron temperatures and densities for this location in the magnetosphere. Measurements of the electron spectrum at higher energies by this instrument and also by the quadrispherical LEPEDEA instrument (Ref. 13) show a significant increase of energetic (keV) electrons over this time period (not shown). The ISEE-1 plasma wave experiment and radio propagation experiment (Ref. 15 and 16) both indicate that the plasma electron density during this period of time was about 1 $cm^{-3}$.

The existence of a negative potential barrier when the spacecraft is either uncharged or at a negative potential requires a mechanism for its formation. There are two possibilities for a mechanism: one is that there is differential charging of the spacecraft surfaces. This can lead to a potential distribution which has a potential barrier more negative than the spacecraft body if there were some isolated surface such as a dielectric also at a more negative potential than the main body. The second possibility is that there is sufficient negative space charge in the vicinity of the spacecraft, produced by the emitted photoelectrons and by the ambient plasma, that a negative potential barrier is formed (Ref. 17 and 18).

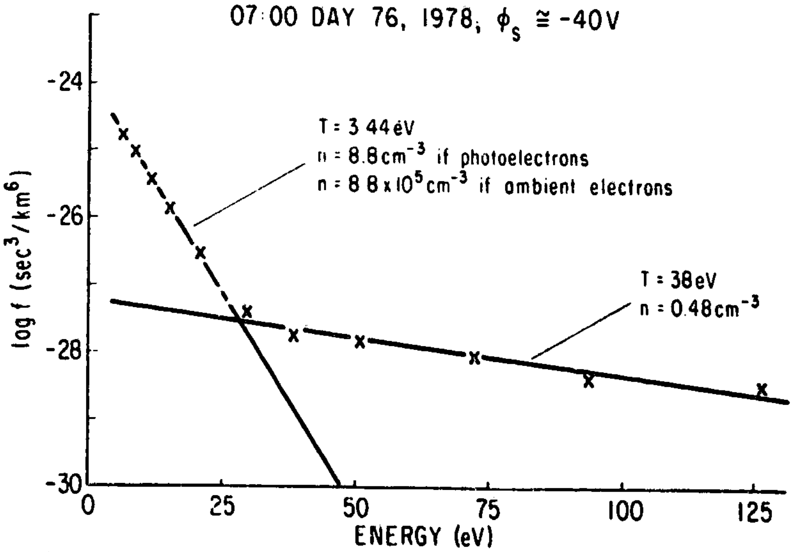

Figure 7. Electron distribution function from the ISEE electron spectrometer at 0700 UT on March 17, 1978.

The situation here on ISEE is somewhat similar to that on ATS-6 where photoelectrons and secondary electrons were observed to be reflected from a potential barrier about the spacecraft when the spacecraft was charged to a negative potential (Ref. 19). In the case of ATS-6, it was shown that the observed potential barriers were too large to be attributed to the effects of space charge (Ref. 20). It was inferred that the barriers must be caused by differential charging. This was later confirmed by detailed calculations (Ref. 8).

It appears unlikely that differential charging can be the mechanism responsible for the creation of the potential barrier around the ISEE spacecraft. The stringent cleanliness specifications that were imposed should have prevented potential differences of more than 1 V between portions of the spacecraft surfaces. The precise magnitude of the potential barrier about ISEE during this event is not known, since the returning photoelectrons were observed at oblique rather than normal angles to the spacecraft surface. However, since photoelectrons were observed to return at energies up to abut 20 eV, it is likely that the magnitude of the potential barrier was at least 10 V. This is too large to be attributed to differential charging if the cleanliness specifications were effective in keeping differential potentials to less than 1 V. Hence we conclude that the most likely mechanism causing the formation of the potential barrier is the presence of space charge.

In the solar wind and in the quiet magnetosphere, the spacecraft potential is usually positive so that low energy photoelectrons would return to the spacecraft anyway, without the necessity for the creation of a potential barrier. The fact that the electric field probes are floating at about +5 V while the spacecraft is at about -70 V during this period does not necessarily imply an inconsistency. If the current balance is between collected plasma electrons and escaping photoelectrons and secondary electrons, then it is possible to have more than one potential at which the net current vanishes (Ref. 21). If the potential barrier has been formed because of the presence of space charge, it is not surprising that barriers have not been formed around the electric field probes which are quite small compared to either the photoelectron or ambient plasma Debye lengths (a few meters and a few tens of meters respectively).

## CONCLUSIONS

(1) We have shown that on March 17, 1978, the ISEE-1 spacecraft charged to a negative potential on the order of -70 V in sunlight. Evidence for the charging were presented from the two electric field experiments on the spacecraft and from the plasma composition experiment. In addition, we showed that the ATS-5 spacecraft charged to a potential of about -6 kV in eclipse about three hours earlier on the same day but in what appeared to be the same plasma environment.

(2) We have shown from the electron spectrometer experiment on ISEE-1 that there appeared to be a potential barrier about the spacecraft during this event. The potential barrier was on the order of 10 to 20 V negative with respect to the spacecraft body, and was effective in returning emitted photoelectrons to the spacecraft.

(3) It is likely that the potential barrier was produced by the effects of space charge rather than by differential charging of the spacecraft surfaces if the

electrostatic cleanliness precautions were indeed effective. Verification of the mechanism responsible for the creation of the potential barrier requires detailed modeling of this event. The modeling should use photoemission and secondary electron yields appropriate for the ISEE-1 surface materials.

We thank a number of ISEE experimenters who have helped us by making their data available and assisting with its interpretation: F. S. Mozer and A. Pedersen with the spherical double probe electric field experiment, J. P. Heppner and N. C. Maynard with the long-wire electric field experiment, L. A. Frank and T. E. Eastman with the LEPEDEA, E. G. Shelley and R. D. Sharp with the plasma composition experiment, K. W. Ogilvie and J. D. Scudder with the electron spectrometer experiment C. C. Harvey with the wave propagation experiment, and D. A. Gurnett and R. R. Anderson with the plasma wave experiment.

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