A STUDY OF ATMOSPHERIC SPACE-CHARGE DENSITY NEAR THE SURFACE OF THE EARTH

by

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ABSTRACT

The purpose of the investigation was to study the atmospheric space charge near the surface of the earth. The effects on the space charge of some atmospheric variables were studied. Space charge of both signs was observed and negative space charge was found to be predominant in the period from March 30 to April 30, 1958, the time during which the study was made. Positive space charge was observed on a few occasions, however. The usual space-charge density was found to lie in the range from -100 to -600 electronic charges/cm^3. Results comparable to those obtained in the course of the investigation have been observed by other investigators in various parts of the world.

A STUDY OF ATMOSPHERIC SPACE-CHARGE DENSITY
NEAR THE SURFACE OF THE EARTH

INTRODUCTION

Because of the ionization of air by natural radioactivity, by cosmic radiation, and, to a lesser extent, by ultraviolet radiation from the sun, there exist in the atmosphere free electrical charges (Table 1). These charges reside on particles which range in size from that of electrons to that of gas molecules, aggregates of molecules, dust particles, and water droplets. In the lower atmosphere, another source of ions which can become very important during times of high convection of the air is dust particles rising from the earth. Due to the potential gradient which exists between the earth and the upper atmosphere, the earth has a high surface charge density. Dust particles rising from the earth are charged as they leave the surface. Ions also are produced by thunderstorms.

In general, a given parcel of air near the ground surface contains both positive and negative ions, with a density of a few hundred to several thousand electronic charges/cm^3. Usually, these positive and negative charges are not present in equal numbers; the excess of those of the one sign over the other gives rise to what is defined as space charge. This space charge may be of either sign and may vary in magnitude from zero to many thousand electronic charges/cm^3. The present investigation is concerned with this space charge: means have been developed for measurement of the space charge and some preliminary measurements have been made.

Table 1. Rate of Production of Ion Pairs[1]
(cm^{-3} sec^{-1})

	Due to natural radioactivity	Due to cosmic rays
Oceanic air	0	2
Country air	8	2
City air	8	2

One piece of evidence which points to the presence of space charge in the atmosphere is the variation with altitude of the electric field which exists between the upper atmosphere and the earth. This system of the earth and the upper atmosphere may be considered as a charged spherical capacitor, with

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[1] T. W. Wormel, "Atmospheric Electricity—Some Recent Trends and Problems," Quarterly Journal of the Royal Meteorological Society, 79, 1953, p 5.

the earth as the center electrode. A potential gradient exists between these two electrodes, and in the absence of space charge, the field between the two electrodes is approximately uniform. In the actual case of the earth and the upper atmosphere, considering the air as the dielectric medium between the two, variations in the field exist. This variation, an example of which is shown in Table 2, indicates that space charge, upon which lines of force may terminate, resides in the air between the electrodes. In general, it is found that this variation is most pronounced in the lower atmosphere in that region where haze is present, indicating the presence of particles larger than gas molecules.

Table 2. Potential Gradient at Various Altitudes[2]

Altitude (km)	0	0.5	1.5	3	6	9
Field (volts/meter)	130	50	30	20	10	5

The air between the plates of the earth-upper atmosphere capacitor is actually a poor insulator because of the presence of ions. The current leakage between the plates of this capacitor

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[2] O. H. Gish, "Atmospheric Electricity," in Terrestrial Magnetism and Electricity, edited by S. A. Fleming, Dover Publications, New York, 1953, p 212.

has been estimated by Gish[3] to be about 1800 amp, directed toward the earth. It has also been estimated that a leakage of this order would almost completely discharge the capacitor in two hours. To maintain the charge on the capacitor, there must be an upward supply current; the accepted view is that this current is generated by thunderstorms. To preserve the electrical balance, the supply current from all thunderstorms over the earth must equal the air-earth current of 1800 amp.

In the lower atmosphere, the sign of space charge has usually been assumed to be positive under normal atmospheric conditions. Positive ions formed by cosmic radiation move downward under the influence of the earth's electric field and enrich the surface air with positive charge. It appears quite likely, however, that during disturbed atmospheric conditions, negative ions coming from the surface of the earth (and residing on dust particles) may easily reverse the sign of the space charge. These negative ions presumably originate principally in the surface charge as a result of the potential gradient. Another source of ions which is of importance in the lower atmosphere is ionization by natural radioactivity in the earth.

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3. O. H. Gish, "Universal Aspects of Atmospheric Electricity," Compendium of Meteorology, American Meteorological Society, Boston, Massachusetts, 1951, p 113.

METHOD AND APPARATUS

Method

In this investigation, the determination of space-charge density involved the use of a space shielded from external fields by a conducting enclosure. Such a shielded enclosure is commonly called a Faraday cage. Air containing the space charge to be measured was allowed to circulate through the walls of the cage, which were formed of copper wire mesh, and the field arising from the space charge was measured. Located at the lower boundary of the Faraday cage, as shown in Figure 1, was an electrode which was sensitive to the fields arising from the space charge within the cage. A sensitive electrometer was used to measure the charge induced on the electrode by the field arising from the space charge. In order that measurements could be made by this means, it was necessary to cover the electrode periodically so that the charge induced on the electrode by the field could be removed. Covering the electrode reduced the field essentially to zero. Re-exposing the electrode to the existing field induced on it a charge proportional to the field strength.

Figure 2, a schematic diagram of the sensing electrode assembly, illustrates the cycle of operations of the space-charge apparatus: Starting with the cover, or shader (S), in a position uncovering the sensing electrode (E), the shader (S) moves into

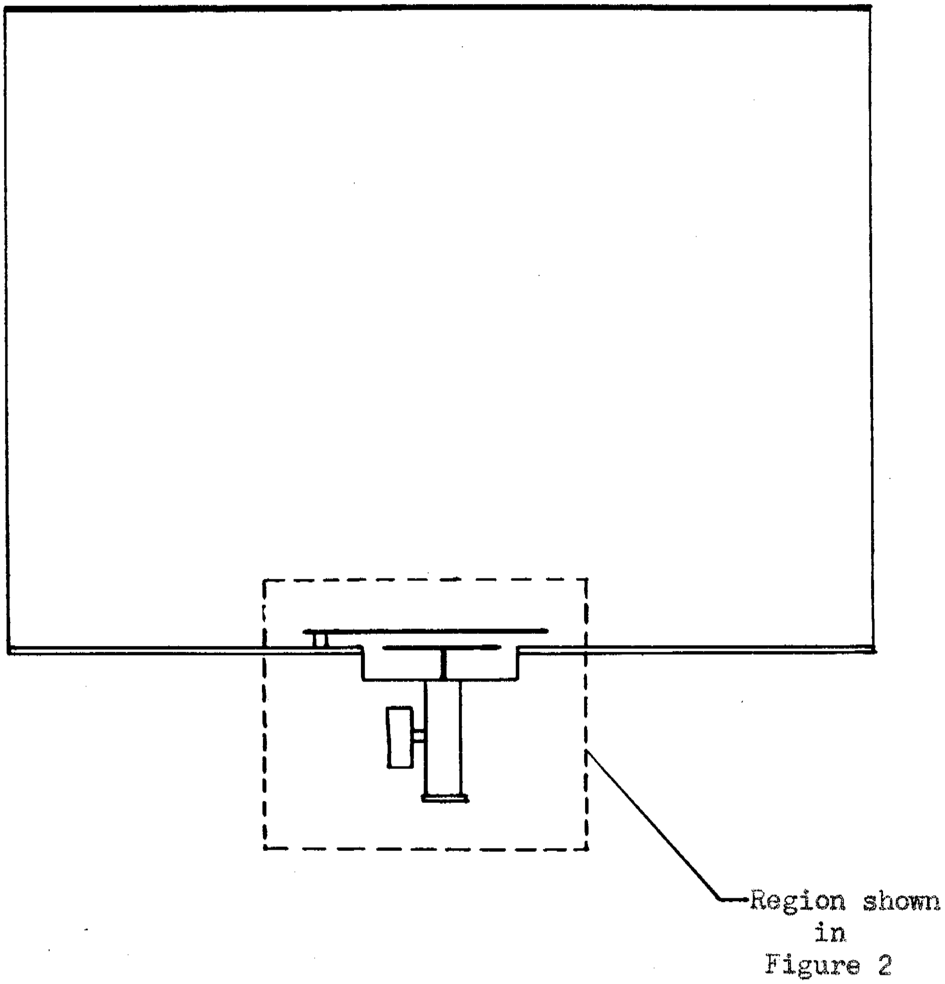


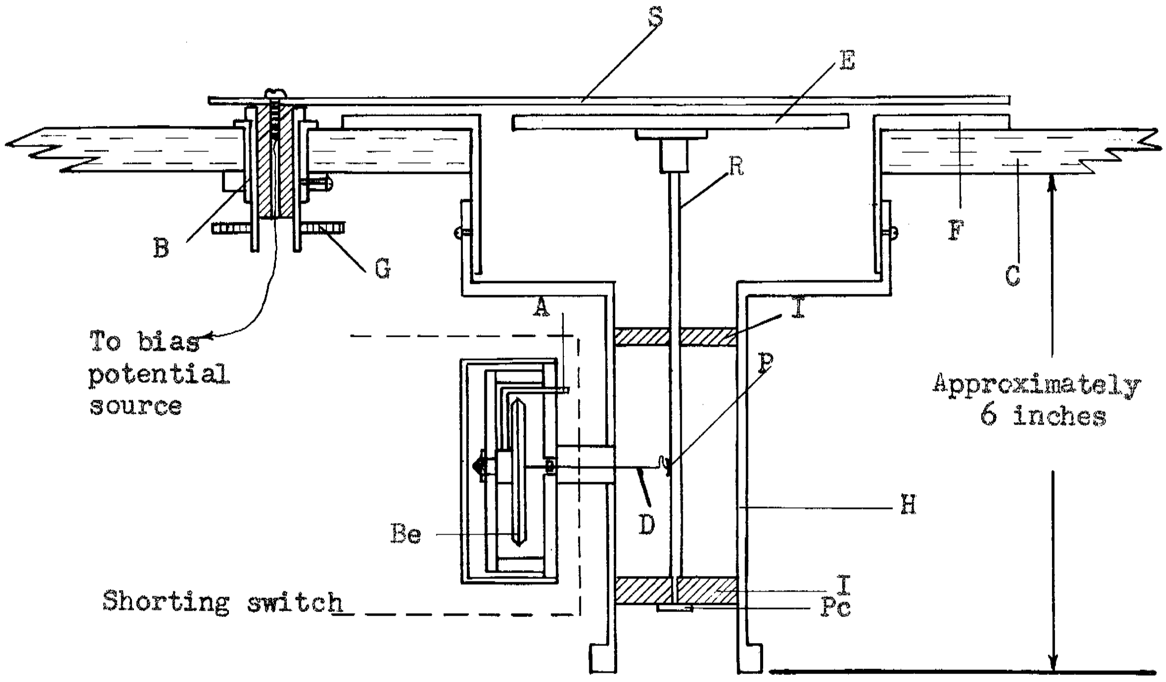
Figure 1. Faraday Cage and Sensing Electrode Assembly

the position shown. During movement of the shader (S) in that direction, a switch (P) is closed to remove the induced charge on the electrode (E). The switch (P) is then opened and the shader (S) is moved away to expose the electrode (E) to the field to be measured. In normal operation, the duration of this cycle is about ten seconds.

To compensate for fields originating inside the cage from sources other than space charge, a small bias potential was applied to the shader, which induced on the electrode a charge equal in magnitude, but opposite in sign, to the charge induced by the stray fields. The stray fields concerned in this study were contact potentials and fields arising from films on the metal surfaces exposed. The surfaces of films on metal are not always at the same potential as the substrata, and contact potentials arise from differences in work function of metal surfaces. This contact potential is a function of the history of the surface, the type of material, the impurities in the material, and various other factors.

Details of Apparatus

1. The Faraday Cage. (Figures 1, 3, and 4) The cage is cylindrical in shape, having a diameter of 1.22 m, a height of 0.91 m, and a volume of 1.07 m^3. The sides are constructed of 1/4-inch mesh copper screen; the top and bottom are of plywood covered with 1/16-inch mesh copper screen. Attached to the bottom plywood member is a cylindrical iron frame inside of which is secured the cylinder of 1/4-inch mesh copper screen,



C - - Base of Cage
F - - Flange
E - - Sensing Electrode
S - - Shader
P - - Platinum Contacts for Shorting Switch
G - - Gear for Shader Movement
Be- - Bellows
A - - Pipe for Expanding Bellows
H - - Housing of Sensing Electrode Assembly
I - - Fluorothene Insulators
Pc- - Electrometer Probe Contact
B - - Bearing Surface for Shader Movement
R - - Copper Supporting Rod
D - - 0.030-inch Drill Rod

Figure 2. Sensing Electrode Assembly

which may be seen in Figure 3. The top of the cage is clamped to the iron frame in such a way that it may be easily removed for access to the interior of the cage for repairs and adjustments.

2. The Sensing Electrode Assembly. (Figures 2 and 4) Located at the center of the bottom of the Faraday cage is the sensing electrode assembly. This unit consists of a flange (F), the sensing electrode (E), and a housing (H). The flange is so constructed that it seats down in electrical contact with the screen forming the bottom of the cage. A portion of the flange projects downward through a hole in the plywood base of the cage. The sensing electrode is a flat, copper disc five inches in diameter. The electrode is supported by a 1/4-inch copper rod (R), which in turn is supported by two fluorothene insulators (I) mounted in a housing of copper tubing. The 1/4-inch copper rod terminates immediately below the lower insulator in such a way that it contacts the electrometer terminal. The housing fits into a recess in the electrometer head and is attached mechanically, as well as electrically, to the guard ring of the electrometer, the function of which will be discussed later. Attaching the housing to the guard ring keeps the cage and the entire sensing electrode assembly, with the exception of the sensing electrode itself and the shader (S), at the potential of the guard ring.

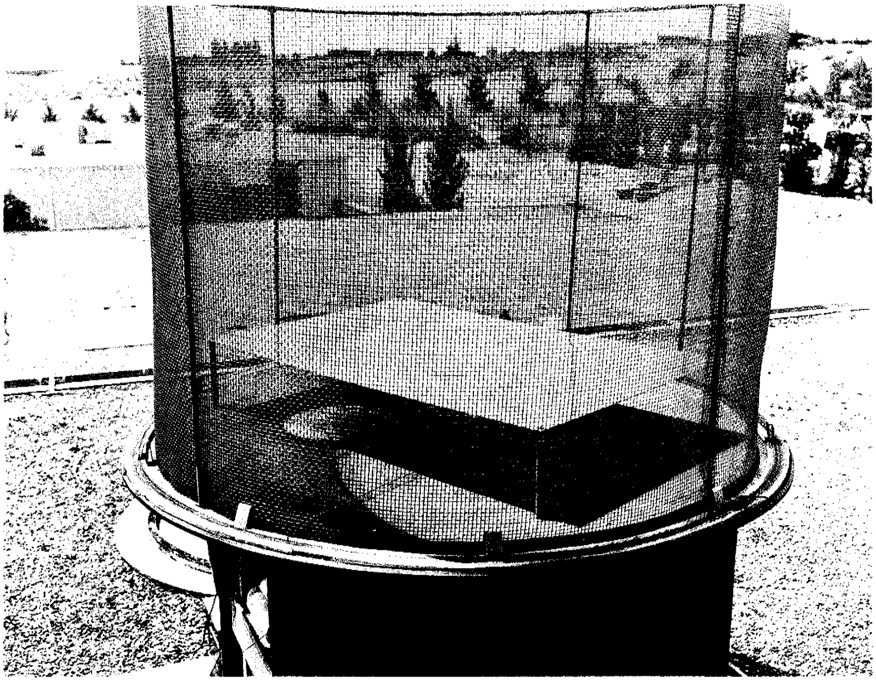


Figure 3. Faraday Cage with Calibrating Plate

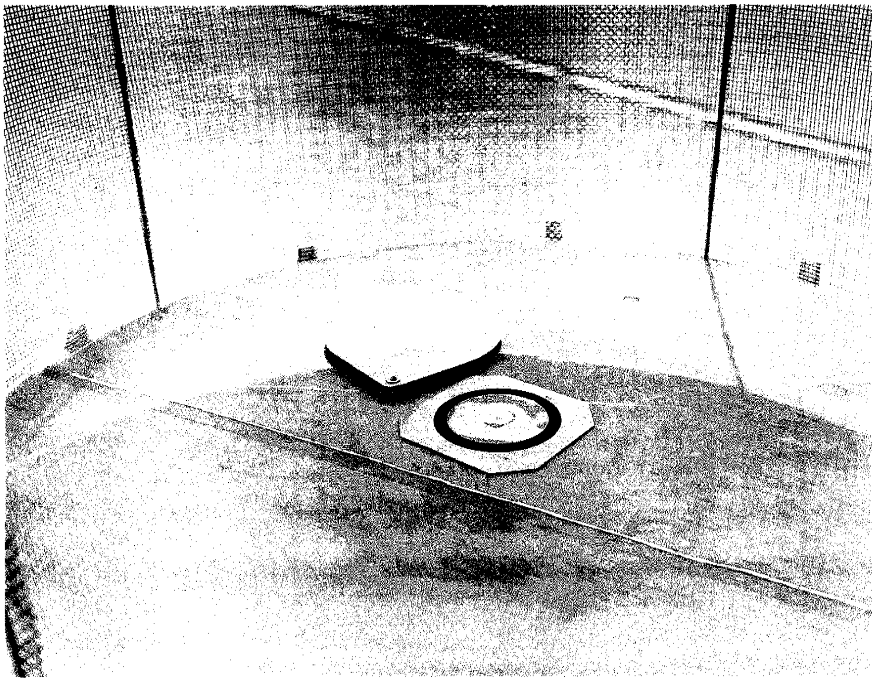


Figure 4. Shader with Sensing Electrode Uncovered

3. Electrometer and Recorder. The electrometer used in this experiment was a vibrating reed electrometer made by the Applied Physics Corporation of California. This electrometer consists of two units: the electrometer head and the amplifier cabinet. Its available ranges are 1 millivolt to 1000 millivolts full scale. The distinctive feature of this electrometer is the vibrating capacitor. This capacitor is formed by the close proximity of an anvil, which is grounded, to a reed to which the input signal is applied. The reed is vibrated by means of a Wien bridge oscillator and is driven at a frequency of 450 cps. A DC potential applied to the reed of the vibrating capacitor results in a 450 cps signal which is applied to the grid of the first amplifier tube. The output of the amplifier goes to a rectifier which operates in synchronism with the Wien bridge oscillator. The signal from this rectifier goes through a cathode follower circuit to a meter which indicates the magnitude of the potential applied to the reed. Also from the cathode follower a signal goes through a feedback circuit. The voltage developed in the feedback circuit is applied to a guard ring surrounding the vibrating reed assembly, maintaining it at the same potential as the reed. Maintaining the guard ring at the potential of the electrometer probe keeps the capacitance of the system at a minimum. The theory of the vibrating reed

electrometer is given by Palevsky, Swank, and Grenchik.[4]

The signal from the electrometer was recorded by a potentiometer-type, Varian recorder. Two chart speeds (2 in./min. and 4 in./hr.) were used during the course of the study. Figure 6 is a section taken from one of the records showing the characteristic trace obtained from the operation of the instrument.

4. The Shader. (Figures 2 and 4) The shader was a flat, tear-shaped, copper plate which could be swung into position over the sensing electrode. When the shader was in position over the sensing electrode, the separation between the two was about 1.5 cm. The shader was operated from below the cage (Figure 2) by a motor-driven gear system meshing with gear G. Also operating off this gear system was a device to squeeze a rubber bulb which actuated the shorting switch.

5. The Shorting Switch. (Figure 2) The term "shorting switch" is used in this discussion in preference to "grounding switch," since the function of the switch was, not to ground the sensing electrode, but to short the electrode to the guard ring, which was at a potential different from ground. Its function was to remove the charge on the sensing electrode. A special switch was made which would not leave a charge on the electrode when the system was unshorted; a rubbing or sliding-type of contact switch would be likely to do this. In this

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[4] H. Palevsky, R. K. Swank, and R. Grenchik, "Design of Dynamic Condenser Electrometers," Review of Scientific Instruments, 18, 1947, pp 298-314.

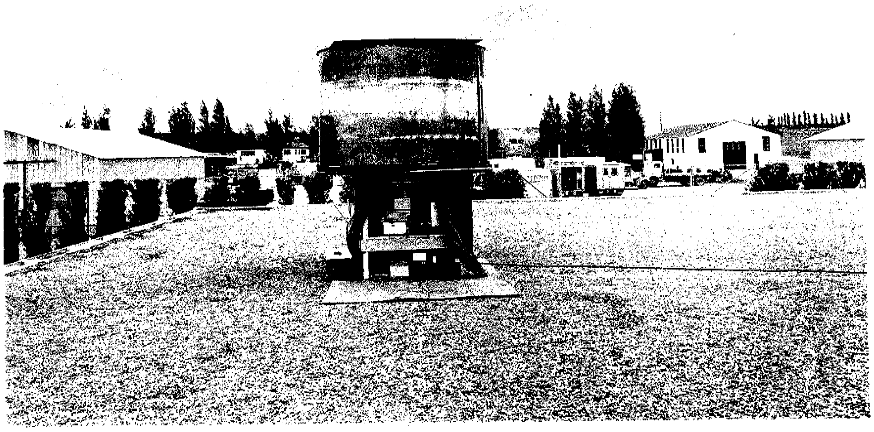
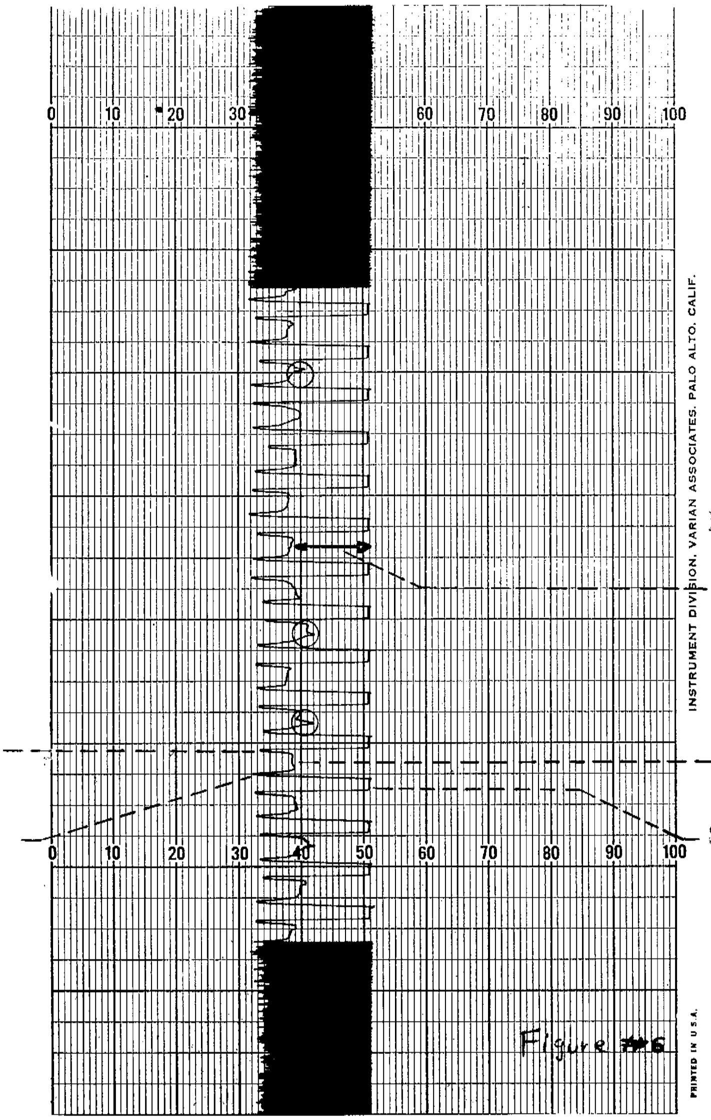


Figure 5. Installation on Roof, with "Can" covering Faraday Cage



Magnitude of effect due to space charge

Sensing electrode uncovered

Shader covering sensing electrode

Shader uncovering sensing electrode

Sensing electrode shorted to guard ring

Figure 6. Section of Record taken by Varian Recorder

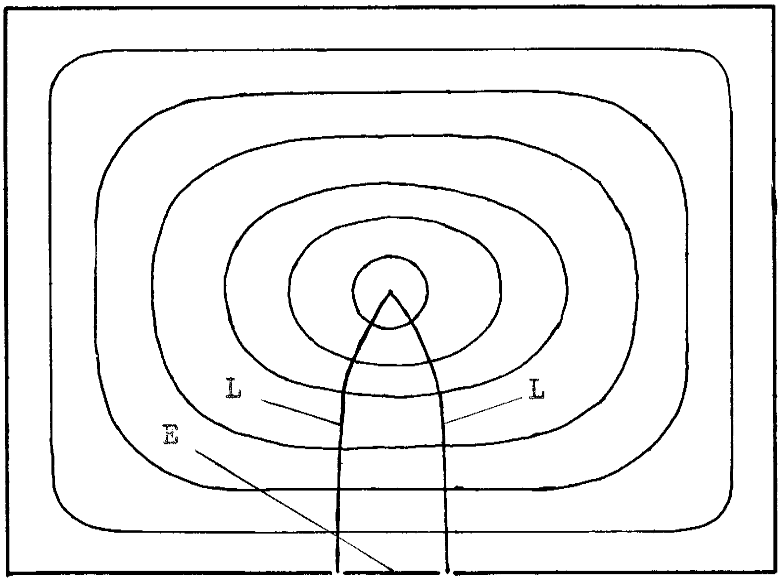


Figure 7. Approximated Equipotentials and Gaussian Volume in Faraday Cage

switch a section of 0.030-inch drill rod (D) was mounted axially on a small disc bellows (Be). Upon expansion of the bellows, an amalgamated platinum contact (P) touched, without sliding, an amalgamated platinum plate on the 1/4-inch shaft (R) supporting the sensing electrode. The bellows was controlled by a rubber bulb.

6. Accessory Equipment. Operating simultaneously with the space-charge apparatus was a three-cup, continuous-recording anemometer. The rotating vanes operated an AC generator, the signal from which went through a rectifier to an Esterline-Angus recorder. During the latter part of the study, an instrument to measure the air-earth electric field was in operation.

Calibration and Adjustment

Contact Potential Bias. For adjustment of the bias voltage applied to the shader, the space inside the cage must be free of space charge, because the presence of space charge produces an effect indistinguishable from the effect of the contact potential. To eliminate space charge, a cylindrical can was constructed to enclose the Faraday cage and to prevent air circulation (Figure 5). With the cylindrical can in position and grounded, a potential of 2400 volts was applied between the sides of the cage and an axial pin, 24 inches in length. With this field, approximately one hour was found to be sufficient to remove essentially all of the space charge. After the space charge had been swept out, the pin was removed and the field measuring apparatus was set into operation. The shader potential was then adjusted to give a null upon unshading.

Upon completion of the adjustment of the shader potential, the cylindrical can was removed and the air allowed to circulate through the cage. The value of the field, then, gave a true representation of the space-charge density in the cage.

The above procedure was repeated periodically to correct any drift which might be present. Generally, variations in the contact potential were small; however, considerable variation was noted when radical disturbance of the shader and enclosure occurred in the course of repairs or after exposure to rain.

Calibration. For interpretation of the data obtained from the apparatus, the scale deflections must be related to the space-charge density in the Faraday cage. A direct calibration of the apparatus, that is, putting a known number of ions into the cage and observing the scale deflection, would be difficult and uncertain due to such factors as recombination and multiplication of the ions. To avoid this difficulty, the calibration was divided into two parts; namely, relating the effect of a field at the electrode to a scale deflection, and relating the space-charge density to the field. These two steps will be discussed separately below.

The first part of this determination, which was to relate the effect of a known field to the scale deflections, was done by placing over the sensing electrode a metal plate, 24 inches by 36 inches, to which a known potential was applied. The metal plate was supported by insulating rods. It stood 14.6 cm above the bottom of the cage, and is shown in place in Figure 3. The cylindrical can was then placed over the cage and the space charge swept out. This done, the shader potential was adjusted to nullify the effect of the new contact potential introduced by the calibrating plate. Potentials of from 20 to 1500 millivolts were applied to the calibrating plate, and their effects on the electrometer were recorded by the Varian recorder. Table 3 shows the magnitude and effects of the applied fields. A check of the contact potential after the calibration had been completed revealed that no change in ion concentration or contact potential had occurred during the calibration.

In relating the space-charge density to the field at the sensing electrode, an approximation was made, in the manner shown in Figure 7, to the field configuration produced by a homogeneous charge density existing in the cylindrical volume of the cage. Gauss' law was then applied to a volume bounded by a surface of rotation defined by lines of force (L) and the sensing electrode (E), enabling calculation of the field strength at the sensing electrode. Disturbance of the equipotential surfaces due to the presence of the sensing electrode does not occur because, as was pointed out earlier, the cage is kept at the same potential as the sensing electrode. There will be, however, a slight disturbance of the equipotential surfaces because of the gap between the sensing electrode and the flange (F in Figure 2). The lines of force which form part of the surface enclosing the volume are chosen in such a way that they intersect the base of the cage at the midpoint of the gap between the sensing electrode and the flange.

In the calculations to follow, the symbols below are used:

dA = the element of surface area of the Gaussian surface (meters^2).

a = the effective radius of the sensing electrode (0.0625 m).

V = the Gaussian volume (meters^3).

E = the average electric field strength at the sensing electrode (volts/meter).

Q = the entire space charge in the volume V (Coulombs).

ϵ_0 = the permittivity of free space (8.8×10^{-12} farads/meter).

ρ = the volume charge density (Coulombs/meters^3).

N = the volume charge density (electronic charges/cm^3).

From Gauss' law we may write

$$\int E \cdot dA = \frac{Q}{\epsilon_0} \qquad (1)$$

The value of this surface integral over the boundary of the volume under discussion is everywhere zero except at the sensing electrode. The value of the integral is then $Ea^2\pi$. Equation (1) now becomes

$$Ea^2\pi = \frac{Q}{\epsilon_0} \qquad (2)$$

whence

$$Q = \pi a^2 \epsilon_0 E. \tag{3}$$

By definition,

$$Q = V\rho \tag{4}$$

Substituting in (3), we then have

$$\rho = \frac{\pi a^2 \epsilon_0 E}{V}. \tag{5}$$

From Figure 7, V was determined, with as high a degree of precision as the method permits, to be $4.5 \times 10^{-3} m^3$. Substituting numerical quantities in equation (5), we then have

$$\rho = 2.4 \times 10^{-11} E \text{ Coulombs/m}^3. \tag{6}$$

Changing units, this becomes

$$N = 148E \text{ electronic charges/cm}^3. \tag{7}$$

In Table 3 are given values N for different values of E obtained in the first step of the calibration. Also given are values of N per division on the Varian chart paper. The mean value of N per division is 38 $\frac{\text{electronic charges/cm}^3}{\text{division}}$.

The error incurred by this approximation was estimated at 15 per cent. Since the variations in the space-charge density for a particular time interval were large, trends, not high precision in the absolute values, are important.

A very satisfactory degree of linearity in the apparatus can be seen in the fifth column in Table 3.

Table 3. Calibration

Applied Voltage (volts	Scale deflection (divisions)*	E (volts/meter)	N electronic charges/cm^3	$\frac{\text{electronic charges/cm}^3}{\text{divisions}}$
1.2	33	8.2	1215	37
1.0	27	6.9	1015	37
0.9	25	6.2	912	37
0.8	22	5.5	810	37
0.7	19.5	4.8	710	36
0.6	16	4.1	608	38
0.5	13.5	3.4	506	38
0.4	11	2.7	405	37
0.3	8	2.1	304	38
0.2	5	1.3	203	40
0.1	2.6	.7	101	39

*(Applied voltage refers to the potential of the calibrating plate; division refers to the unit scale on the Varian recorder chart paper.)

RESULTS

Initially, the space-charge apparatus was operated in the laboratory in order that necessary alterations could be made and so that familiarity with the operation could be attained. Later, the apparatus was moved to the roof of the Research and Development Division Laboratory on the campus of the New Mexico Institute of Mining and Technology.

Data. Measurements with the apparatus in place on the roof began March 30, 1958, and continued until April 30, 1958. Visual observations of weather conditions and other pertinent factors were made periodically during the time the apparatus was operating. These observations included haze concentration, cloudiness, precipitation, wind direction, and possible local sources of space charge, such as dust from road traffic and water from nearby sprinkling systems. In addition to the visual observations, records were kept of relative humidity, and, in the early part of April, a hot-wire anemometer was used to measure wind velocities. After the three-cup anemometer had been installed, a continuous record of wind velocities was kept.

The magnitude of the space-charge density varied greatly, depending largely upon atmospheric conditions. The value of the space-charge density under the usual atmospheric conditions ranged from approximately -100 to -600 electronic charges/cm^3. During periods of high wind, the apparent space-charge density reached peaks of 3000 to 4000 electronic charges/cm^3. During periods of high winds and gustiness, fluctuations in the space-charge density of 50 per cent or more were not uncommon.

When precipitation was present, the apparent values of space-charge density were as high as those observed during high winds, and the fluctuations were very great. In fact, the observed values varied from large (3000 to 4000 electronic charges/cm^3) negative values to equally large positive values.

Short-period fluctuations in the space-charge density of about 10 per cent, which were observable within the five-second sensitive interval of the apparatus, occurred during periods of high wind and gustiness. Some of these small fluctuations can be seen (circled regions) in Figure 6.

A large percentage of the measurements recorded during the time that the space-charge apparatus was in position showed a negative space charge to be present. Positive space charge was recorded on some occasions, however. Four such periods of positive space charge, which are especially noteworthy, will be discussed in some detail below.

The first of these periods of positive space charge occurred April 6 and 7, 1958. A plot of the space-charge density over an 18-hour interval including that period is shown in Figure 8. The initial reversal occurred at 21:30 MST on April 6. In the hours preceding 20:30 MST, a slight wind was recorded. From 20:30 MST, April 6, until 06:00 MST, April 7, there was no appreciable wind, and the sky was clear. Since observation of haze could not be made at night, the haze conditions were recorded in the late afternoon of April 6 and in the early morning of April 7. These observations indicated a less than usual amount of haze was present during this period. The reversal to typical negative space charge came at 05:45 MST on April 7, which was coincident with sunrise.

The second period of positive space charge occurred on April 11, beginning at 01:15 MST. Figure 10 shows the original chart for a 2 3/4-hour interval including the initial reversal from negative to positive space charge. Figure 11 shows a graph of space-charge density covering a 24-hour interval beginning at 08:00 MST on April 10. From 08:00 to 21:30 MST, April 10, there was a slight wind with gusts up to 10 mph. The negative space-charge density during this interval was higher (8000 to 1500 electronic charges/cm^3) than that recorded on most other days when similar atmospheric conditions were observed. There was no appreciable wind from 21:30 MST, April 10, to 08:00 MST, April 11. The reversal from negative to positive space charge occurred at a time when atmospheric conditions were similar to those described during the positive space-charge period of April 6. On April 11, the time required for the reversal from -500 to +700 electronic charges/cm^3 was only one-half hour. The return to typical negative space-charge conditions came in midmorning on the 11th.

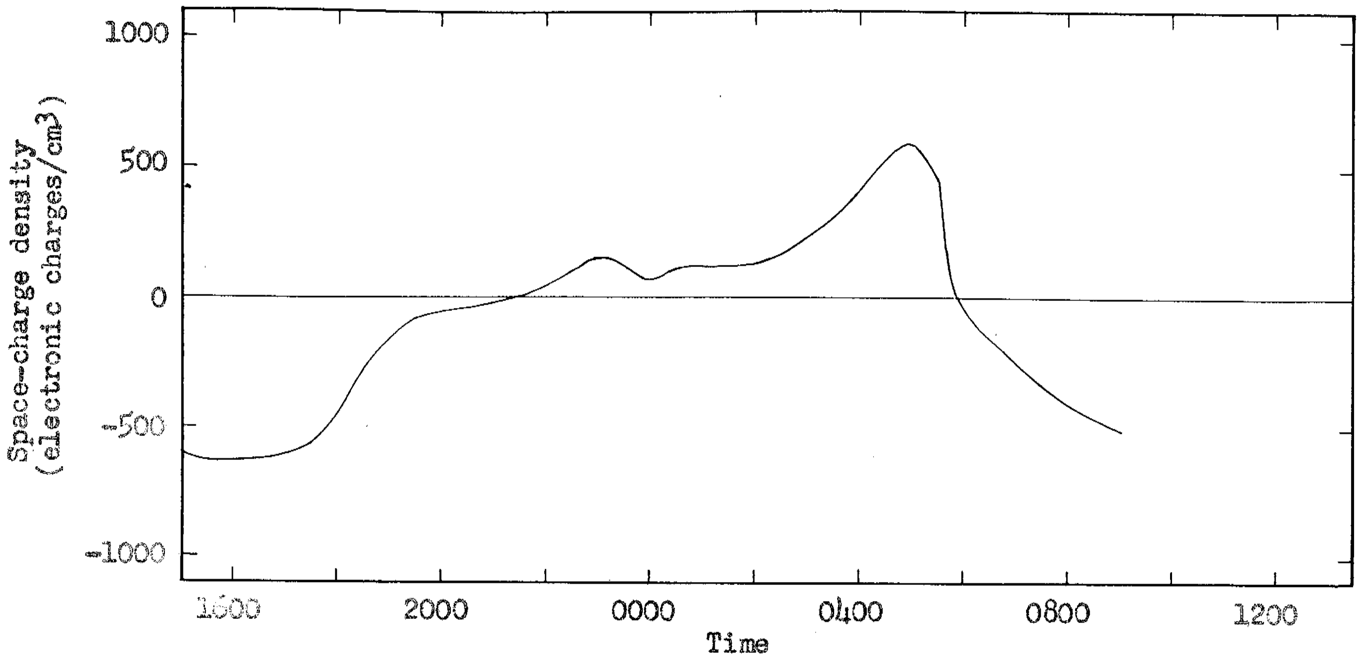


Figure 8. Space-charge Density, April 6-7, 1958

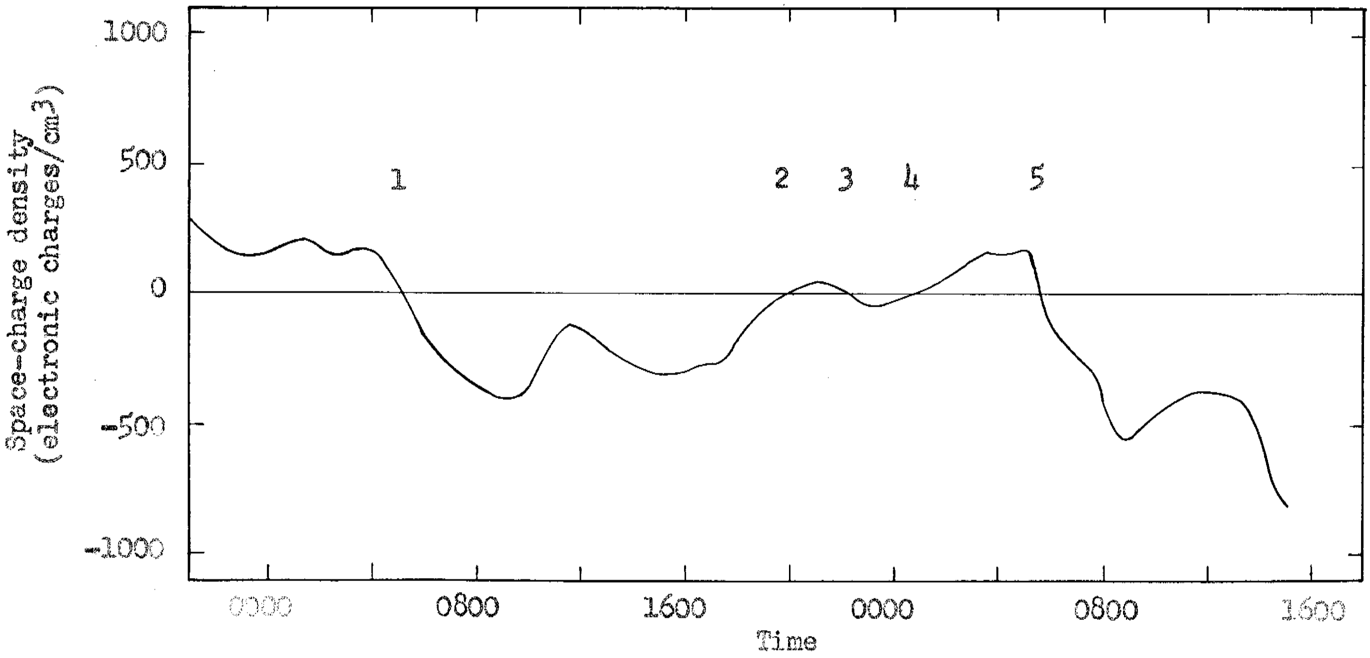


Figure 9. Space-charge Density, April 19-21, 1958

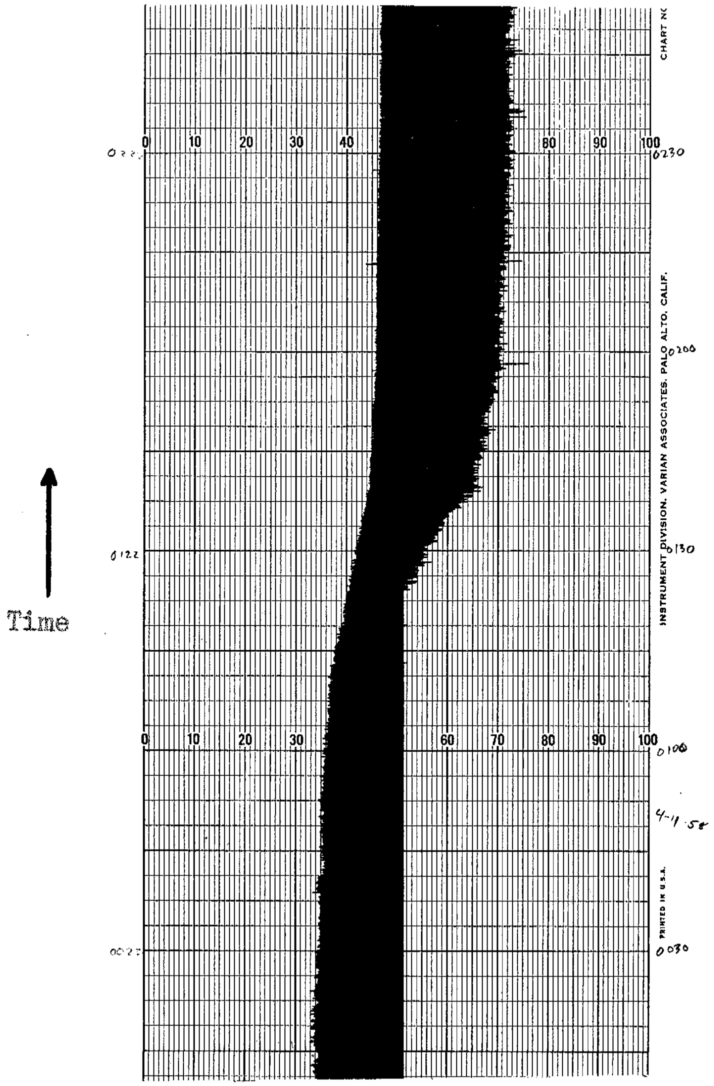


Figure 10. Varian Chart Showing Initial Reversal, April 11, 1958

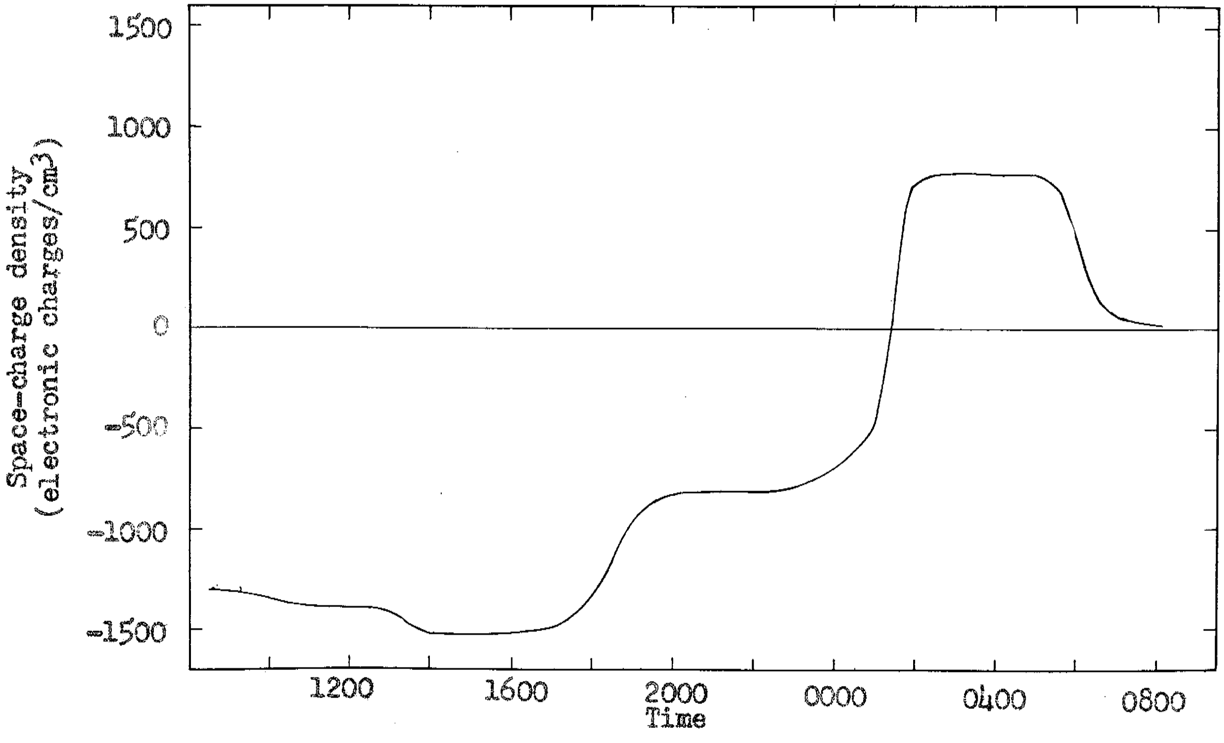


Figure 11. Space-charge Density, April 10-11, 1958

Two more instances of positive space charge occurred during a period of continuous recording of some 42 hours duration, April 19-21. The graph of space charge vs. time is shown in Figure 9. An initial reversal from negative to positive space charge must have occurred before 21:00 MST, April 19, at which time the instruments were started. There was a slight breeze and a clear sky from this time until approximately 12:00 MST, April 20. Reversal No. 1 (Figure 9) to negative space charge was coincident with sunrise, April 20, as in one of the cases previously discussed. The space charge remained negative during the day of April 20 until 20:00 MST. From 12:00 to 16:00 MST, April 20, the wind velocity was almost zero. There were slight winds from 16:00 to 19:00 MST, at which time a calm began which lasted until 07:00, April 21. At 20:00 MST, reversal No. 2 occurred under atmospheric conditions which were similar to those of previous cases. An overall trend between reversals Nos. 2 and 5 was interrupted by a slight fluctuation which appeared as a short period of negative space charge designated by reversals Nos. 3 and 4. Reversal No. 5 from positive to typical negative space charge is seen to have occurred at approximately sunrise (05:30 MST), as on April 7 and April 20. After sunrise, the negative space-charge density showed an increasing trend; after 07:00 MST, this trend was roughly matched by increasing wind velocity and dustiness.

Special atmospheric conditions seem to have been necessary for reversal of the sign of the space charge from negative to positive. In every case where reversals were observed, the atmospheric conditions near the time of the reversal were approximately the same; namely, the wind velocity was zero or very nearly so, the sky was clear, and the haze density appeared to be less than it was at other times during the period of the study.

Discussion. As was mentioned earlier, a large percentage of the data showed a negative space charge to be present. The space-charge densities ranged from 0 to 1500 electronic charges/cm^3 with an average of about 400 electronic charges/cm^3. The general textbook view is that space charge must be positive. This conclusion is reached by an analysis of what has been generally given as the gradient of the field intensity. The magnitude of the space-charge density obtained from this type of consideration is much smaller (20 to 30 electronic charges/cm^3) than that observed in this study.

In actual measurements of space charge, other investigators have obtained results which are similar to those obtained in the course of this study. In Washington, D. C., Gish and Sherman[5] operated simultaneously two instruments for measuring space charge. One of these instruments was located some 15 meters above the other. For the lower instrument, the yearly average space-charge density was determined to be +143 electronic charges/cm^3. For the

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[5] O. H. Gish, "Atmospheric Electricity," op. cit., pp 220-224.

higher instrument, a space-charge density of +111 electronic charges/cm^3 was obtained. Norinder[6] found negative values of space charge on the average both for summer and winter. This work presumably was done in Sweden. Daunderer,[7] in Germany, reported large average values of +1260 electronic charges/cm^3 for summer and -1000 electronic charges/cm^3 for winter. Observations by Obolensky,[8] in Russia, indicated that, on the average, space charge for the months of August and September was negative. Measurements of space charge by use of a Faraday cage, made by Vonnegut and Moore,[9] indicated a predominance of positive space charge, but periods of negative space charge were not uncommon.

The magnitudes of the space charge in the measurements cited above are comparable to those observed during this experiment. All investigators of space-charge phenomena have reported negative space charge at one time or another, even those who found predominantly positive space charge. In all

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[6] H. Norinder, "Researches on the Height Variation of the Atmospheric-electric Potential-gradient in the Lowest Layers of the Air," Geog. Ann., 3, 1921, pp 1-96; 4, 1922, pp 116-121 (cited ibid., p 224).

[7] A. Daunderer, "Luftelektrische Messungen," Physik Zs., 8, 1907, pp 281-286 (cited ibid., p 224).

[8] W. N. Obolensky, "Über elektrische Ladungen in der Atmosphäre," Ann. Physik, 77, 1925, pp 644-666 (cited ibid., p 224).

[9] B. Vonnegut and C. B. Moore, A Study of Techniques for Measuring the Concentration of Space Charge in the Lower Atmosphere, Contract AF 19(604)1920, Final Report of Geophysics Research Directorate, Arthur D. Little, Inc., Cambridge, Massachusetts, January, 1958, pp 61-63.

cases, a radical difference is observed between measured space-charge densities and the values calculated from generalized textbook field intensity data. It seems reasonable to conclude that the space-charge situation needs further investigation.

The abnormally high apparent values of space-charge density (3000 to 4000 electronic charges/cm^3) observed during times of high gusty winds may have been, in part, the result of frictional electrification on the wire mesh of the cage. Experiments conducted to study the effects of frictional and impaction electrification carried on by Richards[10] and Langmuir and Tanis,[11] indicated that such materials as quartz, fluorite, and calcite, impacted on metal, become negatively charged upon leaving the metal. Similarly, high values observed when precipitation was present could have resulted in part from electrification caused by fracturing of the water droplets at the sides of the cage. This electrification also has been observed on field meters.

An attempt was made to obtain a correlation between the anemometer data and the data obtained by the space-charge apparatus, and, in many instances, a close relationship was found to exist

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[10] Harold F. Richards, "Electrification by Impact," Physical Review, 16, 1920, pp 290-304.

[11] Irving Langmuir and H. E. Tanis, The Electrical Charging of Surfaces Produced by the Impact of High Velocity Solid Particles, Army Contract No. W-33-106-SC-65, General Electric Research Laboratory, Schenectady, New York, May, 1945, p 3.

between the two. An example of this relationship, which occurred April 24, can be seen in Figure 12. A broad peak in the neighborhood of 19:45 MST appears on both records. Another such peak occurs at 19:00 MST on both records. Preceding 18:30 MST, a consistent high space-charge density is matched by a general high level on the anemometer records.

An attempt was made to find a correlation between space-charge density and trends in the air-earth potential gradient, but the comparatively small amount of data available offered no basis for correlation. This is not conclusive evidence, of course, and in any event, the principal correlation should be expected with the gradient of the field intensity rather than with the potential gradient. It seems reasonable, however, that there would be some disturbance of the magnitude of the potential gradient at the surface at those time intervals during which large changes in the space charge are taking place.

SUMMARY

The space-charge density in the lower atmosphere was measured by means of a Faraday cage and a sensitive electrometer. During a large part of the time the apparatus was in operation, negative space charge was present, with a density usually in the range from 100 to 600 electronic charges/cm^3. Periods of positive space charge were also observed with charge densities comparable to those of the negative space charge.

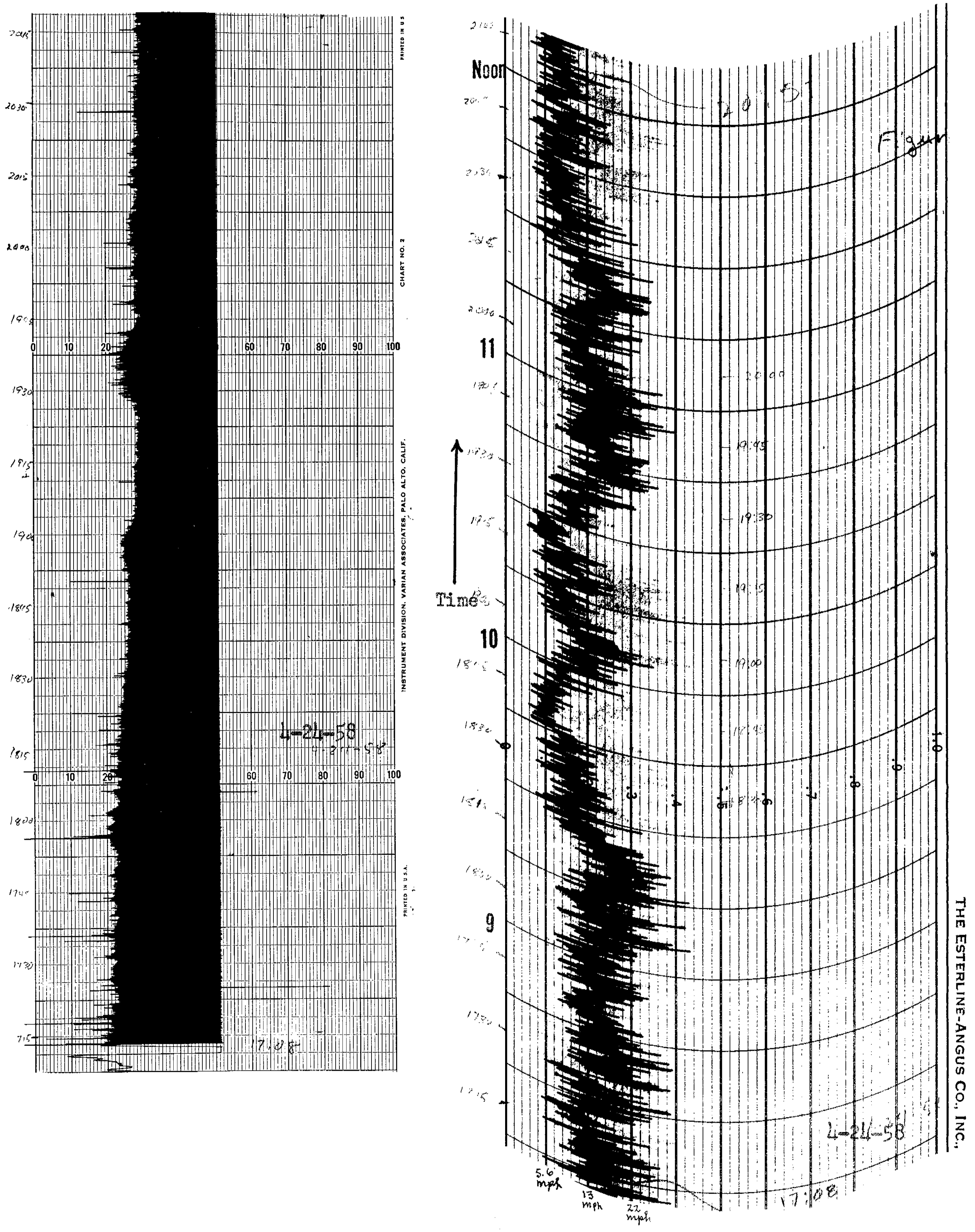

Figure 12. Correlation
between Space Charge (left) and Wind Velocity (right)

The order of magnitude of the space-charge density was higher than was expected, but a search of the literature reveals that the values obtained here are comparable to those observed by other investigators. A possible explanation of the high values obtained is the large amount of wind and dust present during the time the observations were made. It seems probable that clouds of dust coming from the surface of the earth carry large amounts of negative charge; the earth's surface will almost always have a negative surface charge because of the presence of the downward-directed electric field.

Abnormally high apparent values of space charge obtained during high gusty winds and during times of precipitation are thought to be due in part to electrification effects on the sides of the cage.

The space-charge densities observed here are much too high to be consistent with the simple textbook descriptions of the atmospheric electric field. Large gradients of electric-field intensity must be present, at least in limited regions, a conclusion that seems to be in agreement with the results of Koenigsfeld[12] and other investigators who have made actual measurements of the variation of electric field with altitude.

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[12] L. Koenigsfeld, "Investigations of the Potential Gradient at the Earth's Ground Surface and Within the Free Atmosphere," in Thunderstorm Electricity, edited by Horace R. Byers, The University of Chicago Press, Chicago, 1953, pp 24-45.

SUGGESTIONS FOR FURTHER INVESTIGATION

For further investigation of space charge, the following suggestions might be considered. The apparatus should be made more portable and more weather-proof. Studies of the space charge should be made in connection with thunderstorms, at different altitudes on the surface, and at different heights in the atmosphere; for example, with instruments making simultaneous recordings at a number of different heights above the surface. Observations covering long periods of time would be desirable. Studies could be made of the effect of electrification of dust by impaction at the sides of the cage. Laboratory and field studies might be made of the electrification of dust, water vapor, or other particles picked up under the influence of electric fields.

BIBLIOGRAPHY

Gish, O. H., "Atmospheric Electricity," Terrestrial Magnetism and Electricity, edited by J. A. Fleming, Dover Publications, New York, 1949, pp 149-230.

Gish, O. H., "Universal Aspects of Atmospheric Electricity," Compendium of Meteorology, American Meteorological Society, 1951, pp 101-119.

Koenigsfeld, L., "Investigations of the Potential Gradient at the Earth's Ground Surface and Within the Free Atmosphere," Thunderstorm Electricity, edited by Horace R. Byers, The University of Chicago Press, Chicago, 1953, pp 24-45.

Langmuir, Irving, and Tanis, H. E., The Electrical Charging of Surfaces Produced by the Impact of High Velocity Solid Particles, Army Contract No. W-33-106-SC-65, General Electric Research Laboratory, Schenectady, New York, May, 1945.

Palevsky, H., Swank, R. K., and Grenchik, R., "Design of Dynamic Condenser Electrometers," Review of Scientific Instruments, 18, 1947, pp 293-314.

Richards, Harold F., "Electrification by Impact," Physical Review, 16, 1920, pp 290-304.

Vonnegut, B., and Moore, C. B., A Study of Techniques for Measuring the Concentration of Space Charge in the Lower Atmosphere, Contract AF 19(604)1920, Final Report of Geophysics Research Directorate, Arthur D. Little, Inc., Cambridge, Massachusetts, January, 1958.

Wormel, T. W., "Atmospheric Electricity—Some Recent Trends and Problems," Quarterly Journal of the Royal Meteorological Society, 79, 1953, pp 3-50.

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