A DETERMINATION OF THE ATMOSPHERIC POTENTIAL GRADIENT AT MANHATTAN, KANSAS

by

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INTRODUCTION

The study of atmospheric electricity has held a position of importance in the field of scientific investigation for the past half century, and since the beginning of the twentieth century it has become increasingly important principally because of the close relationship that seems to exist between atmospheric electricity, meteorological elements, and radio communication. Most active in this field of investigation is the Department of Terrestrial Magnetism of the Carnegie Institution of Washington, D.C. This department maintains a number of observatories at various places in the world, and for the past twenty-five or thirty years has devoted a great deal of time to ocean work.

While a great mass of data has been obtained during the past fifty years, these data cover only a small portion of the earth's surface since observations have been made at only a few fixed stations. There is, therefore, a real need for multiplying the number of atmospheric-electric stations in order to obtain data which shall contribute toward a solution of the problem of the real significance of atmospheric electricity. These data should be taken at the same time and at stations well distributed over the earth's surface.

In view of these facts and in view of the fact meteorological records are being kept at the Kansas State College, this investigation was undertaken in the hope that it might result in a real contribution to the solution of the problems connected with atmospheric electricity, and especially that it might serve as a beginning of more extended observations in the future.

THEORETICAL CONSIDERATIONS

The study of atmospheric electricity dates back to the time of Benjamin Franklin who established the identity of lightning and static electricity.

The passage of a lightning discharge can only be explained on the assumption that a difference of electrical potential exists between different parts of the atmosphere, or between the atmosphere and the earth, during the progress of a thunder storm. Investigations soon led to the discovery that such potential differences exist not only during the progress of a storm but at all times, no matter what the weather may be.

It was also soon discovered that the potential changes with altitude. This change of potential with altitude is called potential gradient and is measured in volts per meter.

The cause of the potential difference between the surface of the earth and a point above the surface of the earth is found in the fact that the earth is not electrically neutral, but that it carries an electric charge.

Normally its charge is negative, the corresponding positive charge being held by charged dust particles or positive ions in the atmosphere.

Since the atmosphere is a conductor of electricity there is a continuous flow of electric current from the air to the earth, or of electrons from the earth to the air, known as the air-earth current. It is estimated that this current is so large as to carry away about ninety per cent of the earth's charge in ten minutes if there were no way of replacing the loss. This amounts to a current of about one thousand amperes over the whole surface of the earth. The average value of the potential gradient has been found to be about 100 volts per meter, which corresponds to a negative charge on the ground of 3×10^{-4} e.s.u. per square centimeter (19, p. 84). The total area of the earth is 5×10^{18} square centimeters, hence the earth's charge is equal to 15×10^{14} e.s.u. or 5×10^{5} coulombs.

The origin and maintainance of the earth's charge is one of the great mysteries of atmospheric electricity.

Several theories suggesting a solution to this problem may here be mentioned.

Simpson (12, p. 225) has suggested that the sun might emit negatively and positively charged particles. He assumes that the penetrating power of the negative particles is greater than that of the positive particles to such an extent that the negative particles pass through the atmosphere to the earth while the positive particles are caught and held by the atmosphere; the earth's negative charge thus being accounted for. This can not be the correct explanation because the fastest moving charged particles known can penetrate only about nine meters of air at atmospheric pressure.

It is known that moisture condenses on negative ions more readily than on positive ions; hence it was suggested by Wilson (12, p. 224) that falling rain might be the means of maintaining the earth's negative charge. This, however, is contrary to the observed fact that rain brings down more positive than negative electricity.

A theory which gave promise of being successful is one advanced by Ebert (12, p. 224), which makes use of the fact that if ionized air is passed through a fine tube the negative ions diffuse to the wall much more readily than the positive ions. This may be applied to the atmospheric electric problem as follows: as the air found in the capillary tubes of the soil, ionized to quite an extent by the radio active material in the soil, is being drawn out during periods of low barometric pressure the negative ions diffuse to the walls of the capillary tubes, while the positive ions are carried upward by air currents, thus leaving the earth negatively charged. This theory is open to the objection that the ascending positive charge would be neutralized by the time it reached an altitude of about one thousand meters by the negative charge continually going up along with it.

Another theory by Swann (13, p. 404) seeks to find a correlation between the earth's charge and cosmic rays. It is supposed that the cosmic rays, as they pass through the atmosphere, eject electrons from it. Some of these electrons reach the earth and charge it negatively. Swann has disproved his own theory, however, by showing that the current reaching the earth by this means is only about one and one-half per cent of the current which would be required to maintain the earth's charge. It is also estimated that if enough electrons came through the atmosphere to maintain the earth's charge they would produce about one thousand times as much ionization as is actually found to be the case. Thus, we see that this theory also is unable to account for the earth's charge, and the whole problem is still unsolved.

CORRELATED WORK

Atmospheric potential-gradient observations have been made at a number of European stations, but in the United States much less attention has been paid to atmospheric electricity, and potential-gradient data from only a small number of American stations is available. Perhaps the first observer in the United States was Wislizenus (10, p. 113) who made a series of observations during the years 1861-1887 every three hours, beginning at six o'clock in the morning and ending at nine o'clock in the evening.

During the years 1885-1887 observations were made under the general direction of the Chief Signal Officer of the United States Army at the following stations: Washington, D.C.; Boston, Massachussetts; Ithaca, New York; New Haven, Connecticut; Columbus, Ohio; Baltimore, Maryland; and Terre Haute, Indiana.

Potential-gradient observations have been made in recent years by the Department of Terrestrial Magnetism at Lakin, Kansas; Point Loma, California; Green Port, Long Island; Penalosa, Kansas; Washington, D.C.; Stanford University, California; and by the U. S. Coast and

Geodetic Survey at Tuscon, Arizona. The two brief series of observations made in Kansas were made, one in 1918 at Lakin by the Solar Eclipse Party of the Department of Terrestrial Magnetism, and the other in August, 1929, by Wait (14), also of the Department of Terrestrial Magnetism, who wished to secure a diurnal variation series near the geographical center of the United States.

GENERAL RESULTS AND CONCLUSIONS OF PAST INVESTIGATIONS

A brief resume of the general results and conclusions from the existing observational data on atmospheric-electric conditions may be given here. It must be remembered however, that it is for very limited portions of the earth's surface that data are available since observations have been made at only a few fixed stations, hence it should not be supposed that the following conclusions are not open to question.

The average value of the potential gradient is of the order of one hundred volts per meter and increases with altitude, but at decreasing rate until at an altitude of about seven miles no further change is noticed. Its value at that altitude being about 1,000,000 volts.

The potential gradient at the earth's surface is continually varying. Three main types of variations are recognized (19). The first two, the annual and the diurnal variations are more or less regular and periodic; the third is irregular, superimposed upon the other two, and undoubtedly depends largely upon local meteorological conditions.

As regards the annual variation, Bauer (1, p. 383), after having made a study of all available observational data, comes to the conclusion that "for most Stations, both in the northern and southern hemispheres, the potential gradient for October to March, when the earth is nearest the sun, is greater than the mean value for the six months April to September, when the earth is farthest from the sun". That is, there is a maximum in midwinter and a minimum in midsummer. A notable exception however, is the case of one station in Egypt which shows a maximum in midsummer and a minimum in midwinter (19,p.91).

The daily or diurnal variation is a little less simple in character. At most places it is characterized by two maxima and two minima during the day, but in high latitudes there seems to be but one maximum in the early morning and one minimum in the late afternoon. Mauchley (9, p. 80) has recently made an analysis of both ocean and land results and he finds " the diurnal variation of the potential gradient is primarily due to a twenty-four hour "wave" which progresses approximately according to universal time over the entire surface of the earth".

The question as to whether there is any relation between the annual and the diurnal variations of the potential gradient and sun-spot activity was first raised a half century ago by Wislizenus. The latest investigation of this question has been made by Bauer (2, p. 186) who has made an analysis of existing data in an endeavor to ascertain whether any relation exists between solar activity and atmospheric electricity. This study was made with special reference to the two sun-spot cycles between the years 1901 and 1923. He finds that for five of the past seven sun-spot cycles, the potential gradient generally increased with increasing sunspottedness. For the other two sun-spot cycles increasing sun-spot activity apparently had the opposite effect. The question, therefore, is by no means settled and requires further investigation.

The irregular variations superimposed upon the periodic variations are due to various local conditions or meteorological factors such as clouds, atmospheric pollution, humidity, etc.

There are certain meteorological factors which have an annual variation that parallels in a way the annual and daily variations of the potential gradient and it may appear as though the potential gradient variations are dependent upon these factors. These are absolute humidity, temperature, intensity of sunlight, clearness of the atmosphere and atmospheric pressure. The interdependence of these factors has made it difficult to determine the effect that each one has on the potential gradient.

It is generally found that with an increase in absolute humidity there is a decrease of the potential gradient.

In view of the fact that the annual variation of the potential gradient shows a maximum in midwinter and a minimum in midsummer it would seem that there is an inverse relation between temperature and potential gradient. Observations, however, show that no such relationship exists, and the potential gradient is undoubtedly independent of the temperature.

As a rule the potential gradient increases with increase in atmospheric pollution.

The force and direction of the wind do not, as a general rule, affect the potential gradient, except at great velocities the electric field may become disturbed by clouds of dust raised by the wind (5, p. 36-43).

Cumulus and cirrus clouds seem to have no effect on the potential gradient unless they are associated with precipitation. Stratus and nimbus clouds, on the other hand, are quite disturbing. A thick layer of clouds may have the effect of reducing the potential gradient.

Fog has been found to cause the potential gradient to rise to several times its normal value, while heavy precipitation results in high positive or negative potentials (19, p. 99).

DESCRIPTION OF APPARATUS

SET-UP AND OBSERVATION POINT

The essential apparatus used in measuring atmospheric potentials is an electrometer and a collector system. The quadrant electrometer is the most exact measuring instrument now used for measuring differences of potential, and when this research was first begun in the summer of 1932 it was intended to use the Compton quadrant electrometer; but soon after starting the work of calibrating the instrument it was discovered that the Compton electrometer is not designed to operate at sufficiently low sensitivity for atmospheric-electric work. Consequently it would have been necessary to modify the instrument by substituting a much thicker suspension fiber for the original one. Instead of making this change it was decided to use a bifilar electrometer of the "Wulf" type, and such an electrometer suitable for taking eye readings was secured. It is shown diagramatically in Fig. 1, and may be described as follows: The measuring system consists of two thin Wollastin fibers, (A), which repel each other on applying a tension and on being charged with electricity respectively, that is, if a difference of potential against the surrounding metal cylinder, the "Auxilliary conductor", (b) is produced in them. The upper end of the filament is attached to a socket, insulated by amber, to which the charging bar, (C) is screwed, and the lower end of the filament is fastened to an elastic bow (d) of quartz fiber. The auxilliary conductor is insulated against the electrometer cage and is in conductive connection with a terminal (E) on the front plate. By means of a cap screw on this terminal the auxilliary conductor may be connected to the electrometer cage. The cage is fitted with a terminal (F) for earthing. The deflection of the filament is read by means of a microscope and ocular scale. The system is illuminated through a window with a lens in the back wall of the cage. The sensitivity of the instrument is about 5.3 volts per scale division.

Plate I

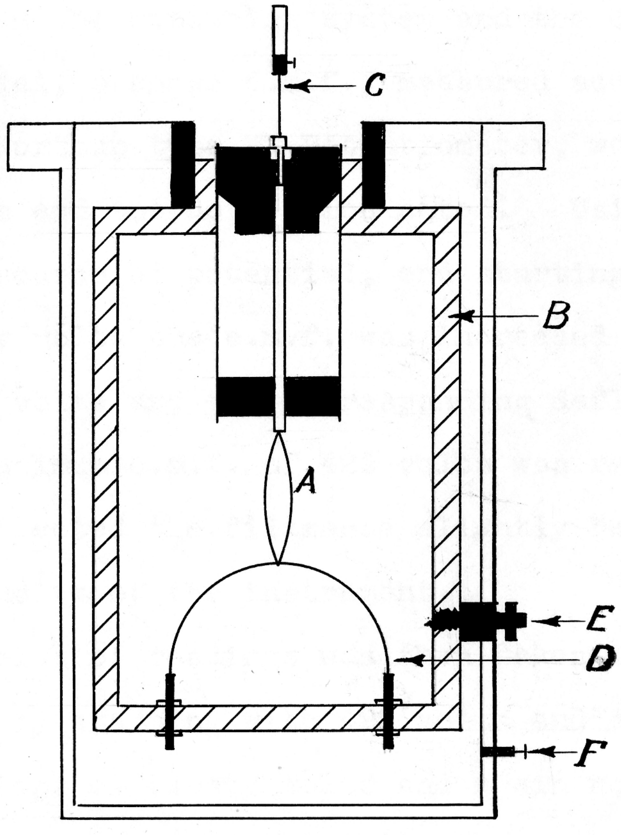

Fig. 1. Cross-sectional view of Wulf electrometer.

The calibration of the electrometer was carried out as follows: With the electrometer cage earthed and the miscroscope so adjusted that the filament appearing at the right of the telescope passed through the zero point of the scale when the measuring system and the cage had an equal potential, a known e.m.f., measured accurately with a Leeds & Northup type K. Potentiometer, was applied to the filaments and the deflection noted. Using B-batteries as a source of potential, and starting with an e.m.f. of twenty volts the e.m.f. was increased in steps of about twenty volts and the corresponding deflection noted until a maximum e.m.f. of 422 volts was reached. This voltage deflected the filaments slightly beyond the registering capacity of the instrument.

Another series of readings was then taken in reverse order; that is, by starting with 422 volts and decreasing the e.m.f. in steps of twenty volts and again noting corresponding deflections of the filaments until the minimum of twenty volts was again reached. The mean of the separate voltages was then plotted against the mean of the corresponding deflections (Fig.2) .

For the collector system the stretched-wire set-up was used, that is two wires were stretched between two vertical poles from which they were insulated by two

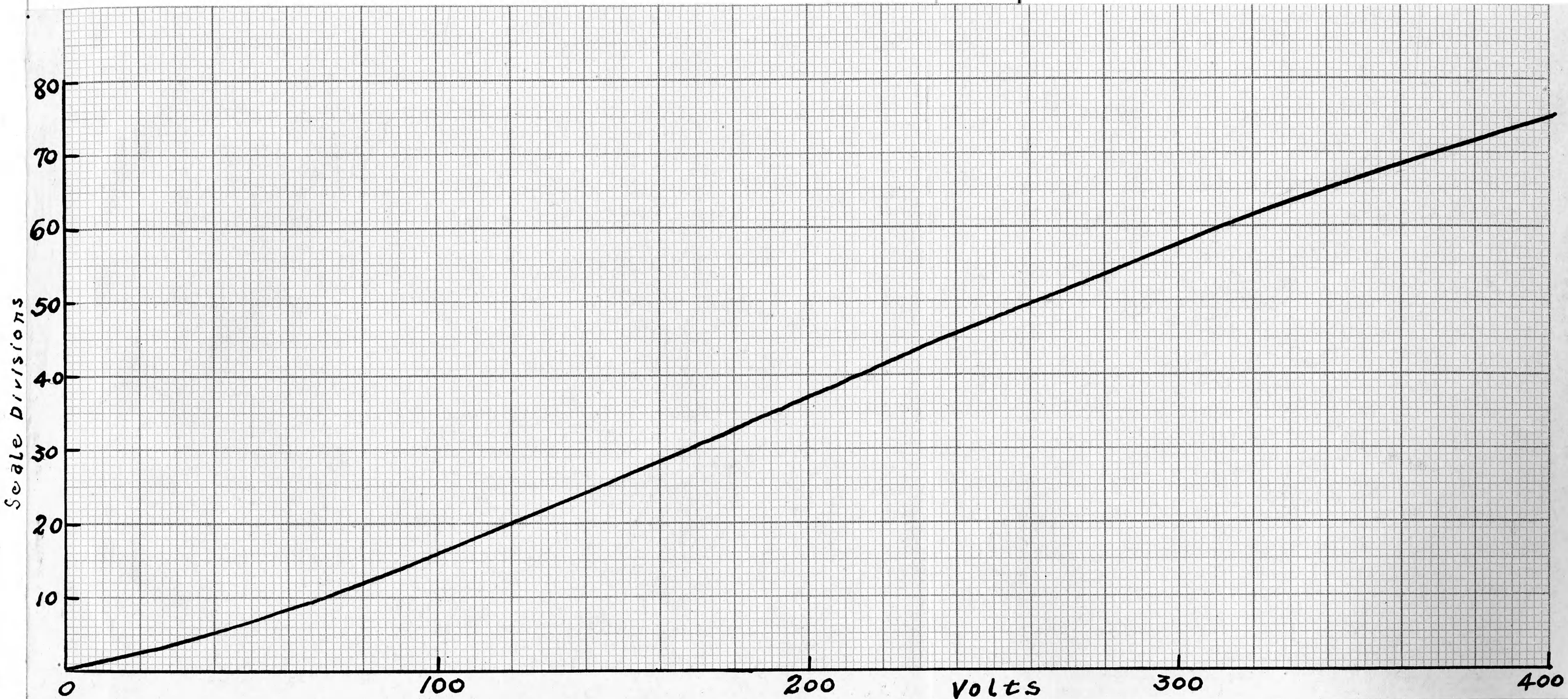

Fig. 2. Calibration curve of Wulf electrometer No. 757.

sulphur insulators, and an ionium collector attached to the midpoint of each wire. In order to maintain perfect insulation at all times the sulphur blocks were scraped occasionally while observations were in progress.

The collectors are the type used by the Department of Terrestrial Magnetism of the Carnegie Institution of Washington, D.C. They consist of a brass disk, two inches in diameter to one side of which a small quantity of ionium is applied by imbedding it in a coat of shellac. A second coat of shellac protects the ionium from the elements.

According to information furnished by the Department of Terrestrial Magnetism, one of these collectors is about four times as active as the other, and on testing them out it was found that the more active collector brought the insulated system to approximately equilibrium value in a little more than a minute while the less active collector required about five minutes. Since the exact ratio was of no value in this investigation, no exact check was made of these constants.

A diagram of the general set-up is given in Fig. 2a. Two poles 2.3 meters high were erected twenty meters apart. As stated above, two fine wires, insulated from the poles by sulphur blocks, were tightly stretched between them;

Plate II

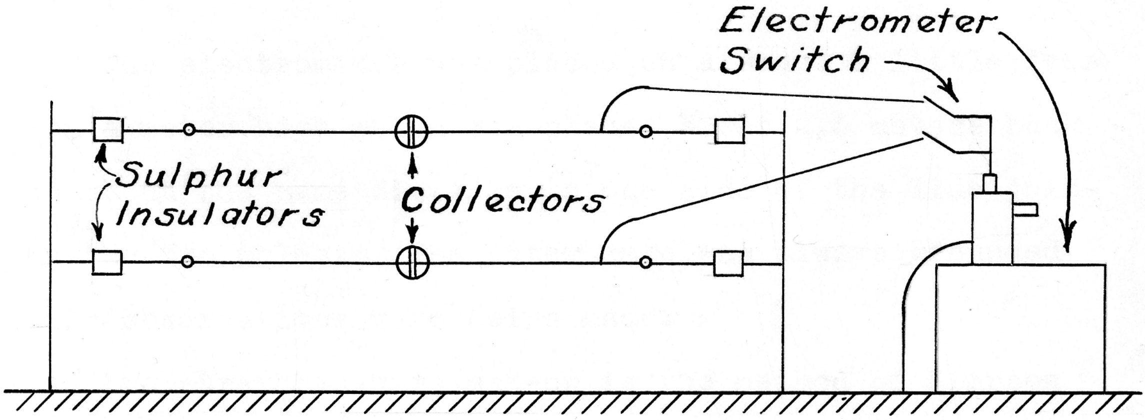

Fig. 2a. Diagram of collector system.

one of the wires being one meter above the ground and the other two meters, and an ionium collector attached to the midpoint of each wire. The wires were connected to the measuring system of the electrometer through a double pole switch by means of fine copper wires. The switch made it possible to connect either wire to the electrometer at any time.

The electrometer was placed on a stand a little less than a meter high which was placed about 2.5 meters back and about the same distance to one side of the line joining the two poles. The outer cage was always grounded while observations were being made.

The stretched-wire set-up is the method of Simpson and Wright and is the one most extensively used in measuring the potential gradient. It consists essentially of keeping a certain portion of the conducting system free from charge, i.e. at the same potential as the air near it. The radio active material on the collector ionizes the air in its immediate vicinity thus making it conductive. This enables the plate to acquire a charge from its surroundings until the field at its surface is zero, i.e. until its potential is the same as that of the atmosphere at the point at which it is located. The whole conducting system is thus brought to the potential of the air next to the collector. The potential recorded by the electrometer divided by the altitude of the wire gives the value of the potential gradient.

As a matter of interest it was decided to determine approximately the rate at which the collector acquires its charge while in the process of bringing the insulated system to equilibrium potential. On an afternoon when air potentials were normal, it was found that when the collector system was discharged and then allowed to charge, the mean rate of change of potential was 3.05 volts per second. The capacity of the collector system was found to be 1.01×10^{-10} farads. Then from the equation $Q = CV$ we have $Q = 1.01 \times 10^{-10} \times 3.05 = 3.08 \times 10^{-10}$ coulombs per second. Assuming that each ion contains one electron, there being 6.3×10^{18} electrons in coulomb, this charge would amount to $3.08 \times 10^{-10} \times 6.3 \times 10^{18} = 19.4 \times 10^{8}$ electrons lost per second.

It was originally intended to make the air potential observations from the Physics building and then to reduce these values to absolute values by means of a reduction factor. An insulating support for the ionium collectors, like the one described by Mauchly and Thomson (8, p.44-45), was constructed and placed outside the window on a wooden support about six feet from the wall of the building. The collectors were connected to the electrometer by means

Plate III Insulating support for
ionium collector.

Plate III

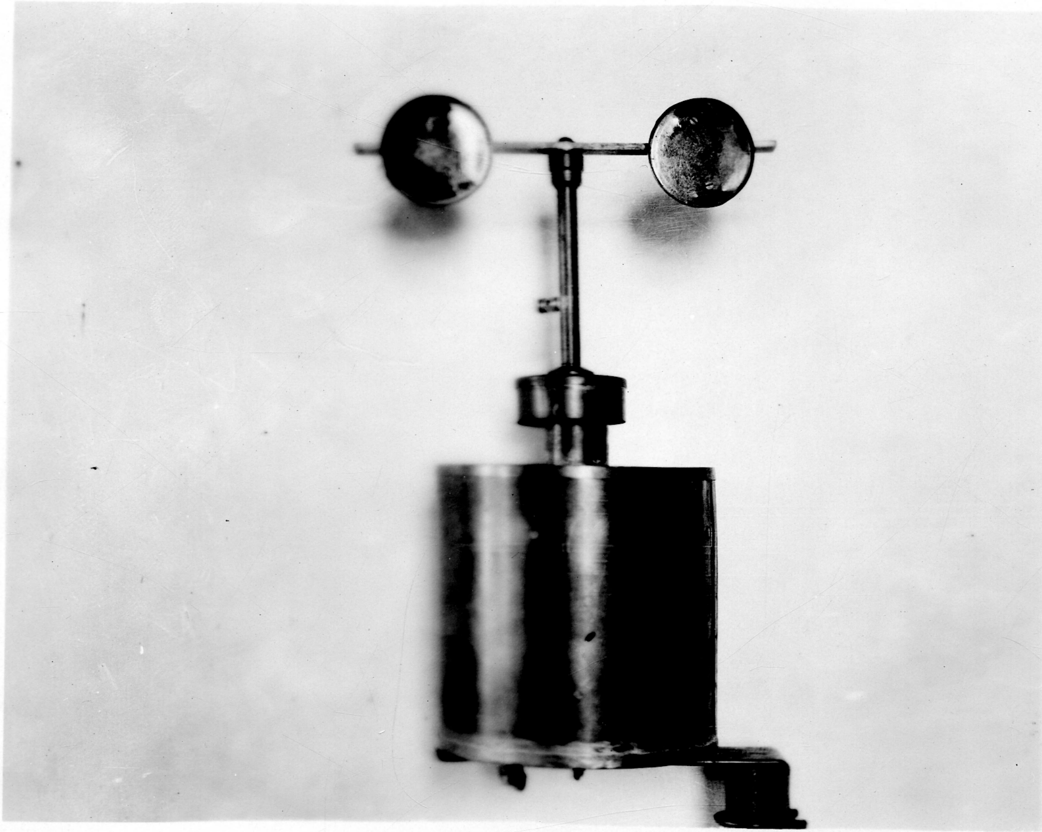

Plate IV Potential Gradient Apparatus.

Plate IV

of a fine copper wire. It was found, however, that the electrometer either fluctuated unduly for brief periods and then stood at or near zero the rest of the time; hence the data thus obtained were valueless and this plan had to be abandoned.

An ideal observation point for making absolute measurements of the potential gradient would be on a large flat plane free from such disturbing influences as buildings and trees. Such a surface is not to be found in the vicinity of Manhattan, and since the station had to be within reasonable driving distance from the college, compromises had to be made. The point chosen is located in a pasture on section 34, Township 9 and range 7. The geographical coordinates of Manhattan are 39° 12' North latitude and 96° 40' west longitude. Height above sea level 1100 feet, the elevation of the observation point is about fifty feet higher.

The particular spot on which the observations were made is a patch of ground about 140 yards long and 100 yards wide, bounded on the north, west and south by a rather deep draw and on the east by the public road. Rolling prairies extend beyond these immediate boundaries except to the south, which is a valley of farm land, planted principally to corn. On the middle of this spot of ground the apparatus was set up as described above. The vegetation here consists of blue stem grass. All tall grass and weeds were removed from an area about ten meters in diameter, leaving only short grass four to six inches tall on the observation point. A clump of low shrubs was about twenty-five meters to the southwest. Vehicles passing by had no noticeable effect on the readings.

In order to see whether a different location would show an appreciable difference in potential gradient values, observations were also made on the flat just north of the serum plant. The topography of the two locations is quite similar, with the exception that the vegetation on the latter was somewhat shorter and a building was located about ninety yards from the observation point. While the potential gradient values here were somewhat lower than on the first location it can hardly be said that the difference was due to the change in locations. The data obtained at this point, those on June 19 and 23, are therefore not treated separately.

According to Gish[1] of the Department of Terrestrial Magnetism, the per cent of error introduced

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[1]MEMORANDA on the Selection of Stations for Absolute Potential-Gradient Observations. O. H. Gish, April 12, 1928.

by an isolated object such as a tree or a house is equal to $100\left(\frac{h}{d}\right)^3$ where h is the height of the object and d the distance from the point of observation to the center of the object. A long row of trees or a fence produce a distortion equal to $100\left(\frac{h}{d}\right)^2$ per cent, where again h is the height and d the distance to the object. Dome-shaped elevations or cup-shaped depressions produce rather large distortions. A cup-shaped depression may arise from clearing grass from about the station; in order to avoid an error greater than 5 per cent, the diameter of the clearing should be about forty times the average height of the vegetation, while the diameter of the clearing should be at least two hundred times the height of the surrounding v egetation if distortions greater than one per cent are to be avoided.

From these considerations it is evident that an error of less than 5 per cent is difficult to avoid except on elaborately prepared sites.

While normally the earth carries a negative charge it may happen that under certain abnormal conditions, for example, when a cloud carrying a negative charge passes over the observation point, a positive charge may be temporarily induced on the ground. The electrometer is not so constructed as to indicate the sign of the charge either on the collector or on the ground. It frequently happens during normal fluctuations of the positive potential gradient, that the electrometer reading drops to zero and then rises again. It behaves in a similar manner if the potential is suddenly reversed from positive to negative. So no matter whether photographic records are obtained or whether the instrument is read at stated intervals, the observer is at a loss to know whether the potential indicated by the electrometer at any given moment is positive or negative.

In order to determine the character of the earth's charge it is only necessary to connect a battery, a 40-volt B-battery was used in this case, in series with the electrometer cage and the ground. If, with the negative terminal of the battery connected to the cage and the positive terminal to the ground, the potential registered by the electrometer is increased, we know that the earth carries a negative charge and the atmosphere a positive charge.

The explanation is as follows: Assuming the filaments to be charged positively and the cage negatively, as they would be if the earth were negative and the atmosphere positive, then with the negative terminal of the battery connected to the cage, the cage would become more negative and repel electrons from the filaments, leaving them more positively charged and the deflection of the filaments would increase. On the other hand if the original charge on the filaments were negative and the cage positive, the negative terminal of the battery would tend to neutralize the charge on the cage, thus permitting some electrons to escape from the filaments, leaving them less negatively charged with the result that the deflection would decrease. The action is similar to that of an ordinary electroscope.

DATA TAKEN

After making several short preliminary runs, observations were taken on the following days: May 29, 2:15-6:15 P.M.; May 30, 10 A.M. - 4:50 P.M.; May 31, 6:15 A.M.-2:15 P.M.; June 2 and 3, twenty-four hour run; June 19 and 23, 10 A.M. - 4 P.M. Only the data complete for the hours 10 A.M. - 4 P.M. have been retained for discussion in this paper. This includes the data taken on May 30, June 3, 19 and 23, 1933.

The general method of observation was to observe the deflection produced on the electrometer scale by the wire, one meter above the ground, and then to switch over to the wire two meters above the ground and observe the deflection produced by it. Readings were taken at five-minute intervals except on May 30, when the instrument was read at two-minute intervals.

Meteorological observations and measurements were made of temperature, relative humidity, direction and velocity of the wind, form and amount of clouds. The wind velocity was determined once each hour with a Keuffel & Esser anamometer; a Lloyd hygrodeik was used to determine the relative humidity. Relative humidity and temperature observations were made every fifteen minutes.

The weather was generally fair throughout the series with the exception of June 23, when about three-fourths of the sky was overcast with thin clouds. The day could, however, be considered as electrically undisturbed, except for a very short interval at twelve o'clock and another at one o'clock when small clouds precipitating a small amount of rain passed overhead. The prevailing direction of the wind was south, and the maximum velocity recorded was 11.3 miles per hour. At no time during the series could the fluctuations of the potential gradient be ascribed to the effects of the wind. The air was remarkably free from pollution such as dust and smoke, and practically no insullation trouble was experienced from insects or flying spider webs.

The deduction of a diurnal variation curve was beyond the scope of this investigation and for that reason only one twenty-four hour series of observations was made. It is evident that conclusions drawn from one such series would be entirely unreliable. The discussion will, therefore, be limited to a very few factors, viz. variation of potential gradient with time, temperature and relative humidity.

DISCUSSION OF DATA

The plan of presenting the data is as follows: The observations of June 23 are taken as typical of the observations made on any one day of the series and are shown in tables 1 and 2 and Figures 3-8. Table 3 and Figures 9-13 show the mean hourly values of the observations made on May 30, June 3, 19 and 23. The tabular and graphical treatment of the data is the same as that for June 23, with the exception that the five-minute readings are not tabulated or shown graphically.

Table 1 shows the form used in tabulating observational data in the field. In this table, as in other tables where they occur, the column headings Def_1 and Def_2 refer to deflections produced on the electrometer scale by the wires one meter and two meters above the ground respectively. P_1 and P_2 are the values of the scale divisions in volts.

Figure 3 shows very clearly the oscillating character of the potential gradient. The curve approaches the type

Table 1

Observed values of potential gradient and meterological data taken
June 23, 10 A.M. - 4 P.M.

Time	Def_1	Def_2	P_1	P_2	TEMP. Dry	TEMP. Wet	Rel. Hum.	Wind Dir	Wind Vel mi/h	Clouds Amt.	Clouds Form
A.M.											
10:00	7.3	19.0	57	114	101	76	32	SE	1.9	Sky over	
05	7.0	18.5	56	112							
10	6.0	17.0	51	105						cast with	
15	8.0	19.5	61	117	99	75	33				
20	8.0	19.5	61	117						thin clouds	
25	10.0	25.0	71	143							
30	7.0	21.0	56	124	98	74	33				
35	6.0	17.0	51	105							
40	5.7	15.3	49	97							
45	4.5	12.0	43	80	98	74	33				
50	3.3	9.7	35	70							
55	4.5	12.0	43	80							
11:00	5.0	12.0	45	80	100	72	25	W	2.6		
05	3.0	7.3	33	57							
10	3.7	11.0	38	75							
15	3.5	10.5	37	73	98	71					
20	4.0	11.0	40	75							
25	3.7	10.0	38	71							
30	3.0	9.0	33	66	97	71	27.5				
35	2.7	8.0	30	61							
40	2.5	7.7	29	59							
45	2.0	7.3	25	57	97	70	25.5				
50	0.0	0.0	0	0							
55	.5	1.5	10	21							
P.M.											
12:00	2.5	7.5	29	58	97	70	25.5	S	4.4		
05	3.0	8.5	33	63							
10	4.0	11.5	40	78							
15	5.0	12.5	48	83	98	70					

Table 1 continued.

Time	Def_1	Def_2	P_1	P_2	Temp.		Rel. Hum.	Wind		Clouds	
					Dry	Wet		Dir.	Vel. mi/h	Amt.	Form
P.M.											
12:20	5.0	14.5	45	93							
25	5.0	14.5	45	93							
30	6.0	16.5	51	103	100	70	22			Sky over-	
35	5.2	15.0	48	95							
40	6.0	17.0	51	105							
45	6.0	16.0	51	100	101	72	25			cast with	
50	4.0	9.0	40	66							
55	4.0	9.0	40	66							
1:00	0.0	0.0	0	0	102	71	21			thin clouds	
05	4.5	13.0	43	85							
10	4.3	11.0	42	75							
15	4.7	13.5	44	88	103	71	20	S	3.7		
20	5.0	13.3	48	87							
25	3.5	10.5	37	73							
30	2.5	8.0	29	61	105	73	22				
35	5.0	12.5	45	83							
40	2.0	6.0	25	51							
45	3.0	9.7	33	70	106	73	21				
50	4.0	12.5	40	83							
55	3.0	9.5	33	68							
2:00	4.7	11.7	44	79	105	72	20	S	3.3		
05	4.0	11.5	40	78							
10	6.5	17.3	53	106							
15	6.0	15.0	51	95	105	71	18				
20	4.0	12.5	40	83							
25	5.3	15.0	47	95							
30	5.5	15.0	48	95	106	71	17				
35	5.5	15.5	48	98							
40	5.5	15.5	48	98							
45	5.0	14.7	45	94	106	71	17				
50	5.0	14.7	45	94							
55	5.0	14.0	45	90							

Table 1 continued.

Time	Def$_1$	Def$_2$	P$_1$	P$_2$	Temp. Dry	Temp. Wet	Rel. Hum.	Wind Dir.	Wind Vel. mi/h	Clouds Amt. Form
P.M.										
3:00	5.5	14.3	48	92	103	70	18	S.W.	4.8	Sky over
05	5.0	14.3	45	92						
10	5.7	14.7	49	94						cast with
15	5.0	12.5	45	83	104	71	19			
20	4.0	10.0	40	71						thin clouds
25	4.5	13.0	43	85						
30	3.0	9.5	33	68	100	68	17			
35	3.0	9.0	33	66						
40	3.7	11.7	38	79						
45	3.0	8.0	33	61	99	67	17			
50	4.0	13.0	40	85						
55	4.0	12.0	40	80						
4:00	3.9	9.0	33	66						

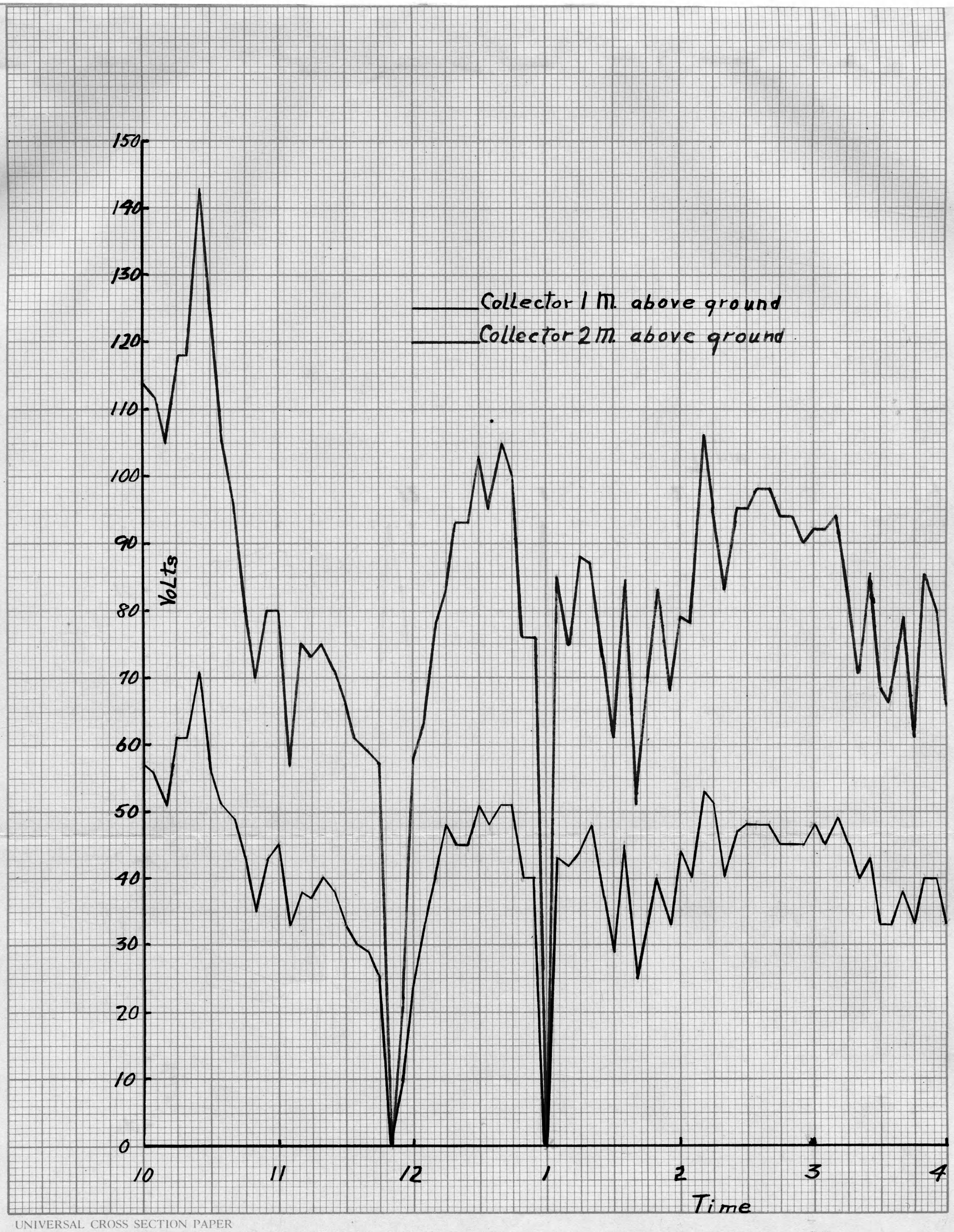

Fig. 3. Variation of potential gradient on June 23, 10 A.M. - 4 P.M.

Table 2

Mean hourly values of potential gradient (P) and meteorological factors as observed on June 23, 1933, 10 A.M. - 4 P.M.

Time	P_1	P_2	Temp. °F	Rel. Hum. %	Wind mi/hr		Clouds Amt. Form
10-11	53	105	90	33	1.9	SE	Sky
11-12	30	58	98	26	2.6	W	overcast
12-1	43	84	93	24	4.4	S	with clouds
1-2	35	69	104	22	3.7	S	all day
2-3	38	76	106	24	3.3	S	
3-4	43	85	102	24	4.8	SW	
Means	40	80	99	25.5	3.5		

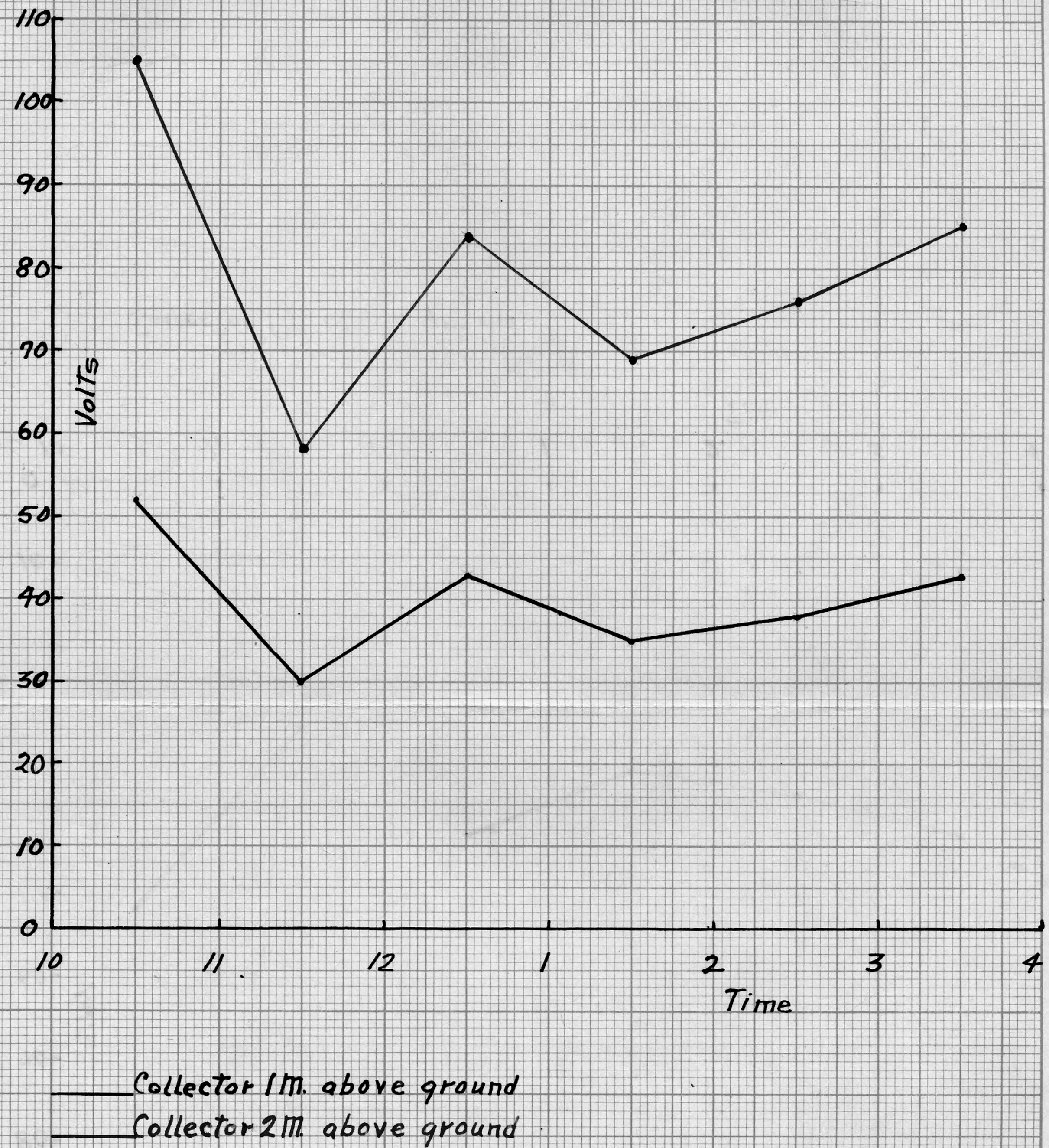

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Fig. 4. Hourly variation of potential gradient June 23, 10 A.M. - 4 P.M.

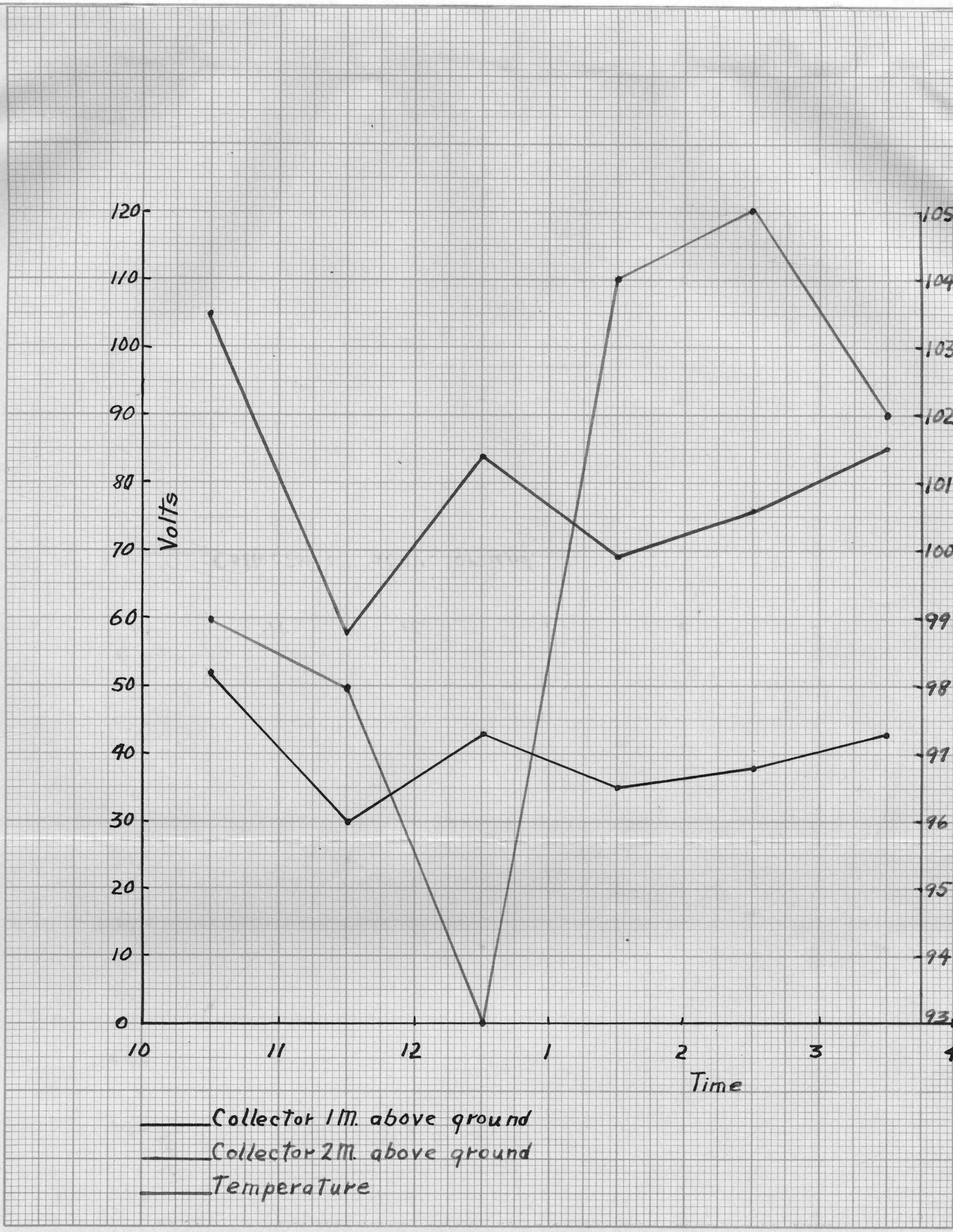

Fig. 5. Hourly variation of potential gradient and temperature with time, June 23, 10 A.M. - 4 P.M.

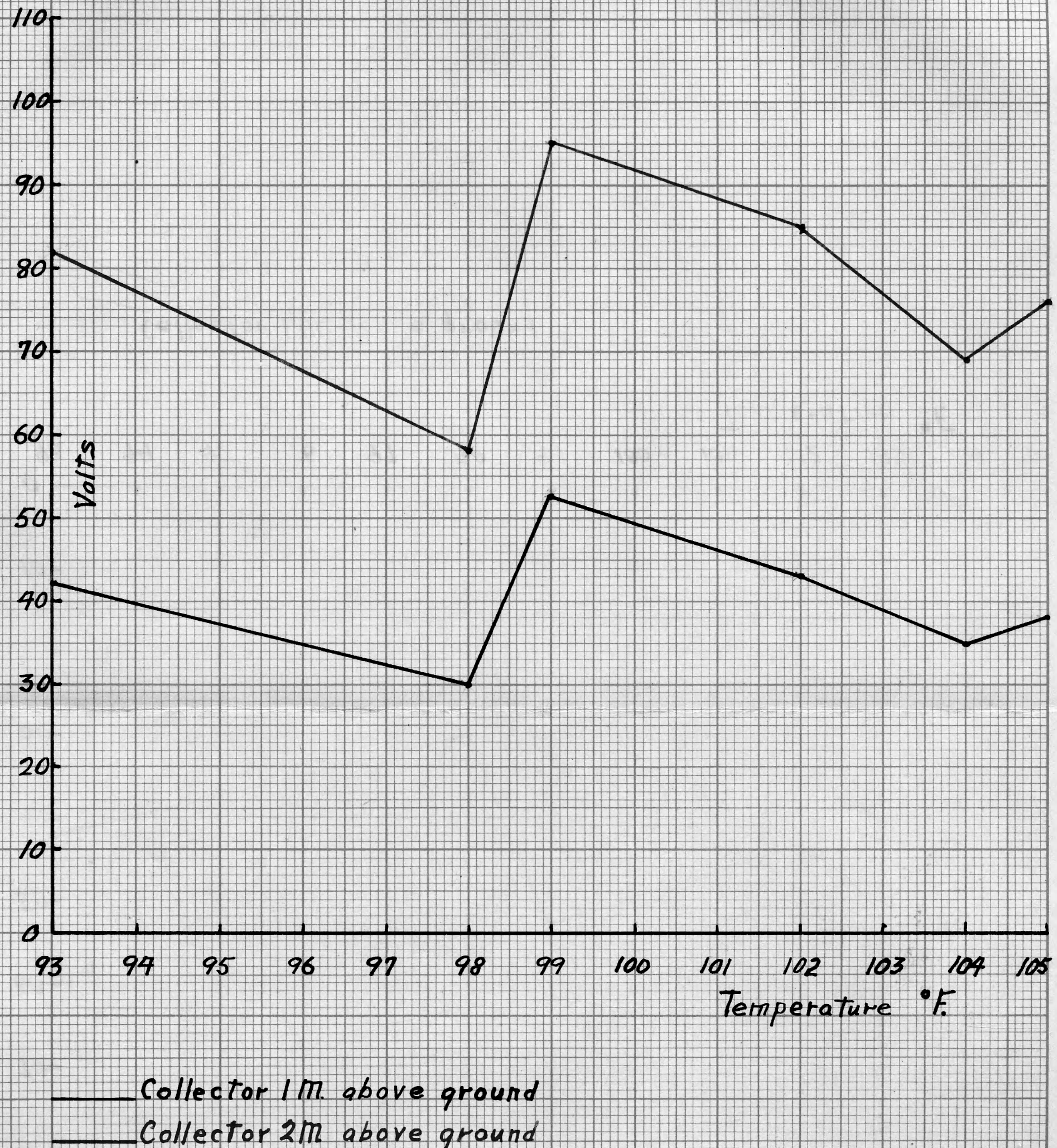

Fig. 6. Variation of potential gradient with change in temperature, June 23, 10 A.M. - 4 P.M.

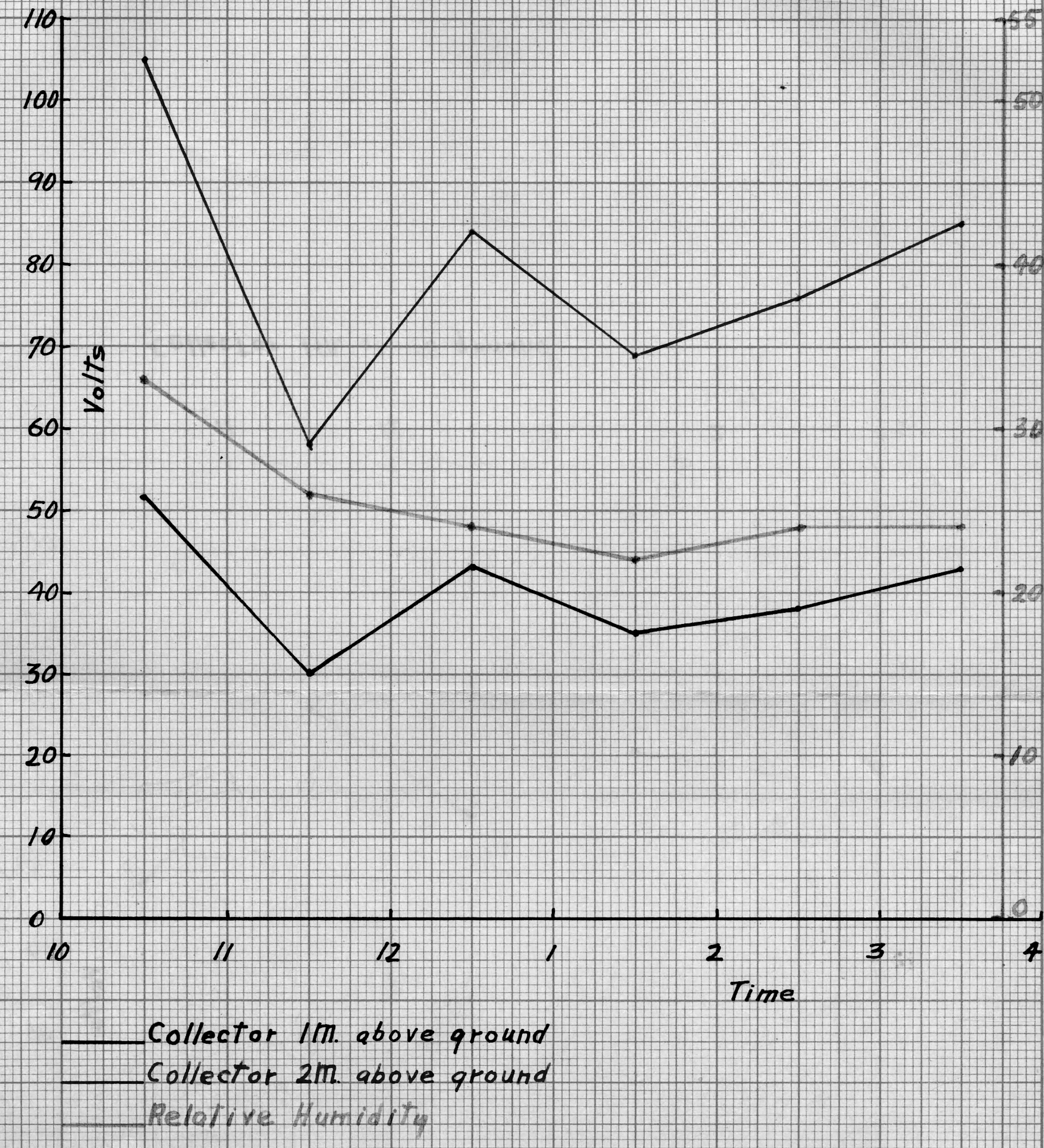

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Fig. 7. Hourly variation of potential gradient and relative humidity, June 23, 10 A.M. - 4 P.M.

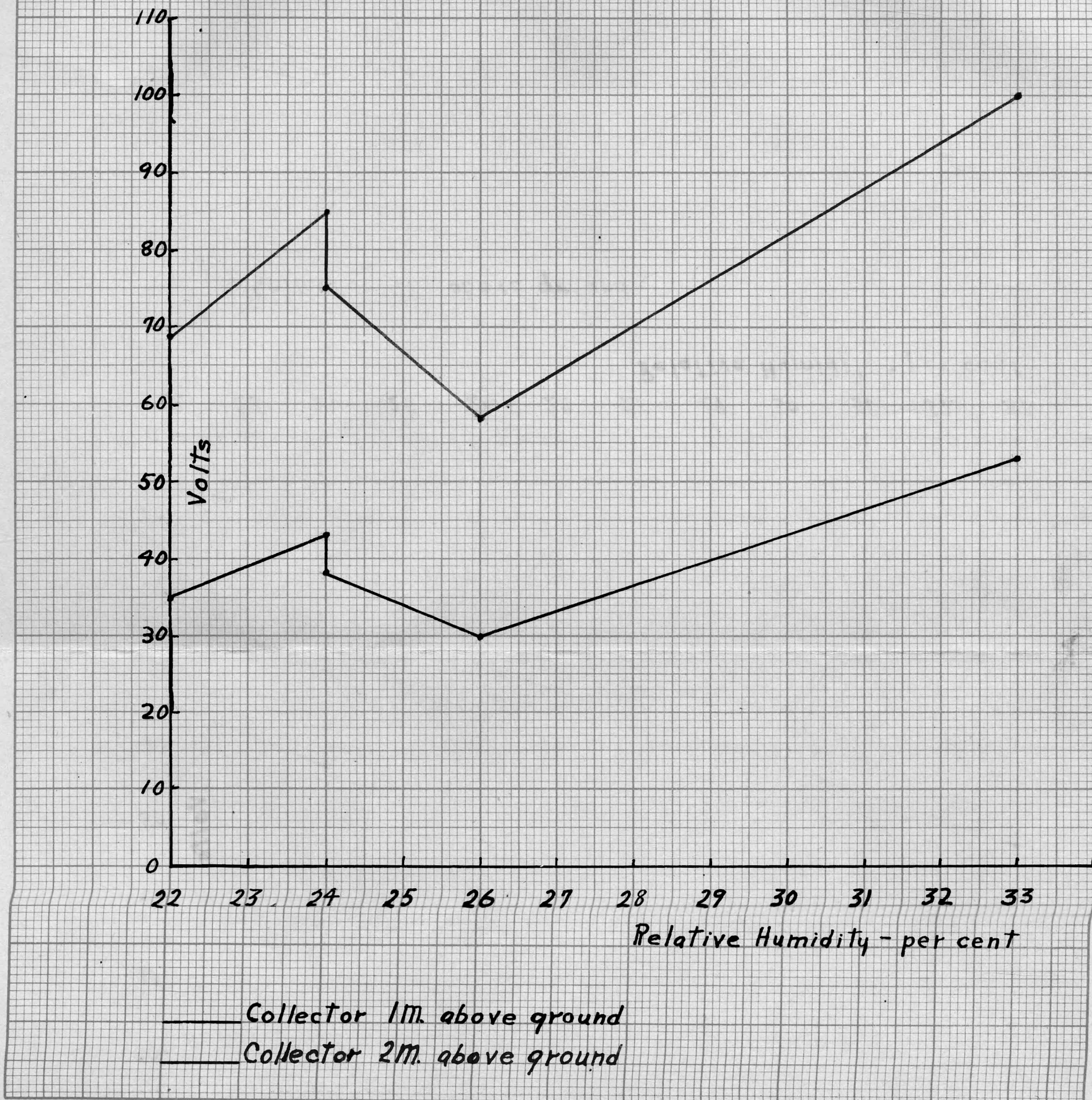

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Fig. 8. Variation of potential gradient with change in relative humidity June 23, 10 A.M. - 4 P.M.

Table 3

Mean hourly values of the potential gradient, temperature and relative humidity for the four days, May 30, June 3, 19 and 23, 1933, 10 A.M. - 4 P.M.

	10 - 11				11 - 12				12 - 1			
Date	P_1	P_2	Temp	Rel Hum	P_1	P_2	Temp	Rel Hum	P_1	P_2	Temp	Rel Hum
	Volts	Volts	°F	%	Volts	Volts	°F	%	Volts	Volts	°F	%
May 30	63	115	74	47	72	130	75	47	62	121	78	42
June 3	78	115	84	51	59	114	87	51	57	112	90	49
19	18	44	92	34	20	48	96	31	57	100	97	27
23	53	105	99	33	30	58	98	26	43	84	93	24
Means	52	95	87	41	45	88	89	39	55	104	90	36

	1 - 2				2 - 3				3 - 4			
Date	P_1	P_2	Temp	Rel Hum	P_1	P_2	Temp	Rel Hum	P_1	P_2	Temp	Rel Hum
	Volts	Volts	°F	%	Volts	Volts	°F	%	Volts	Volts	°F	%
May 30	68	126	79	40	75	140	79	42	74	136	80	42
June 3	47	97	91	47	43	86	92	44	47	93	92	43
19	77	149	100	24	75	137	99	25	34	77	99	23
23	35	69	104	22	38	76	106	24	43	85	102	24
Means	57	110	94	33	58	110	94	34	50	98	93	33

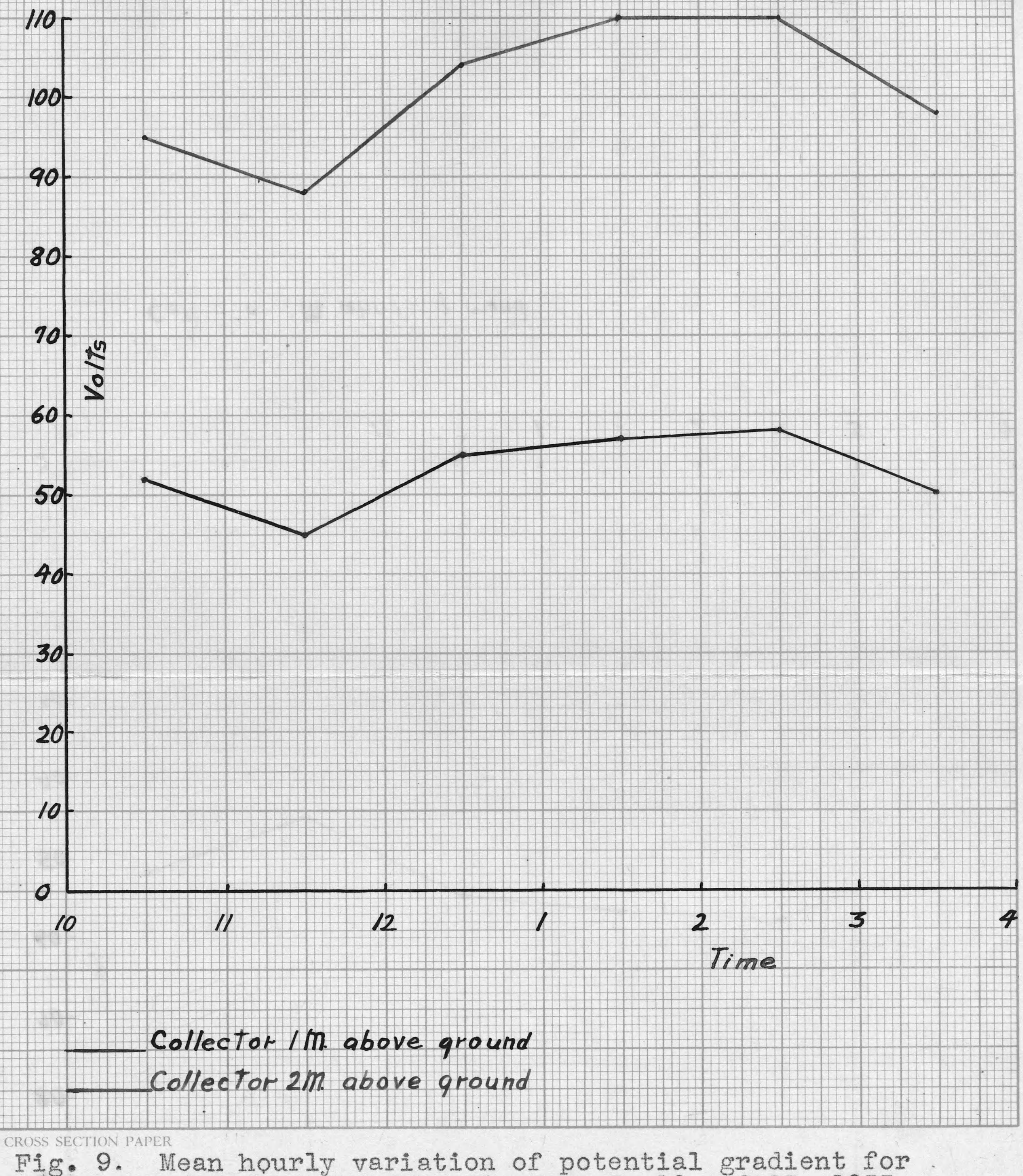

Fig. 9. Mean hourly variation of potential gradient for the four days, May 30, June 3, 19 and 23, 1933 10 A.M. - 4 P.M.

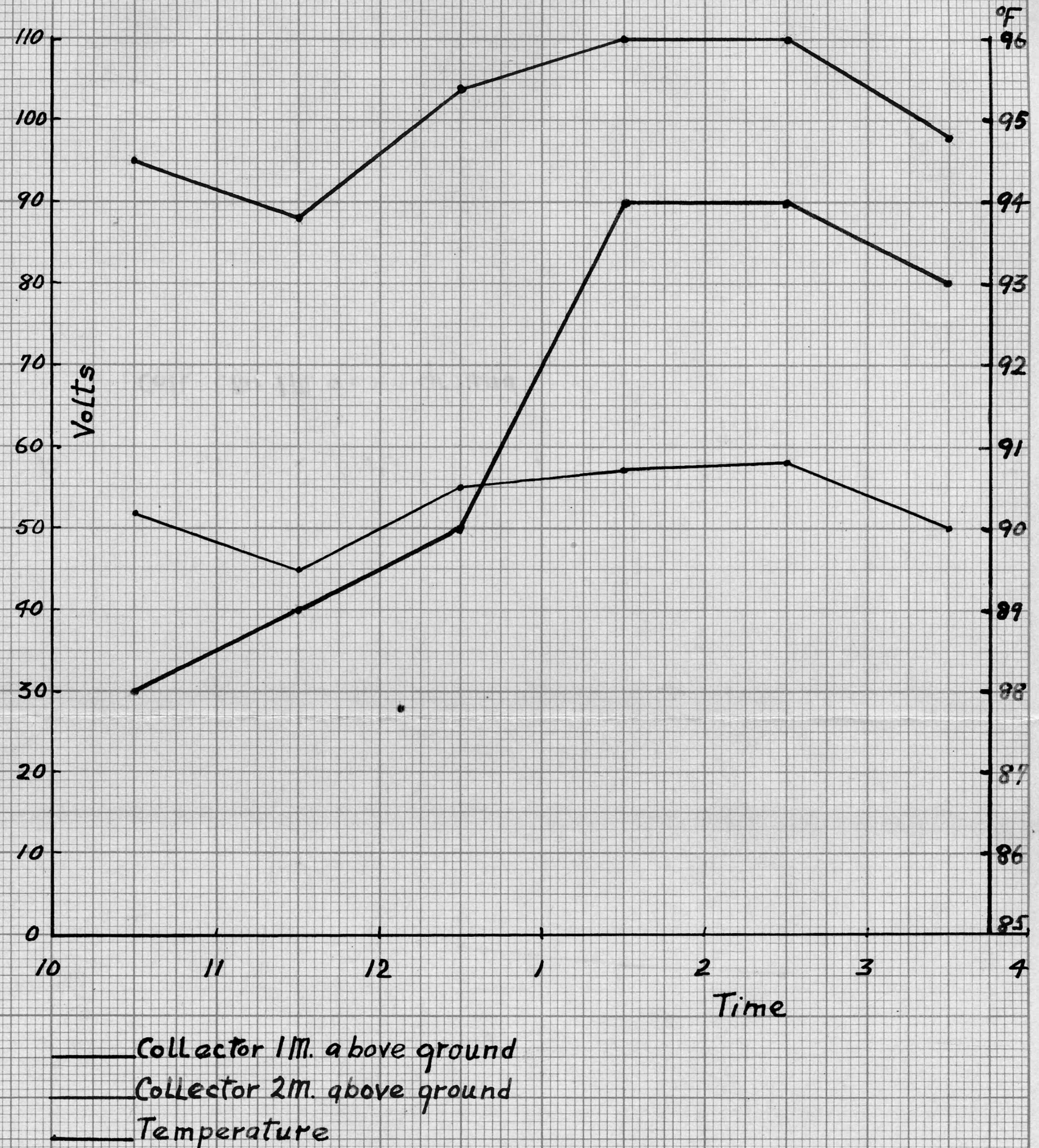

Fig. 10. Mean hourly variation of the potential gradient and temperature for the four days May 30, June 3, 19 and 23, 1933 10 A.M. - 4 P.M.

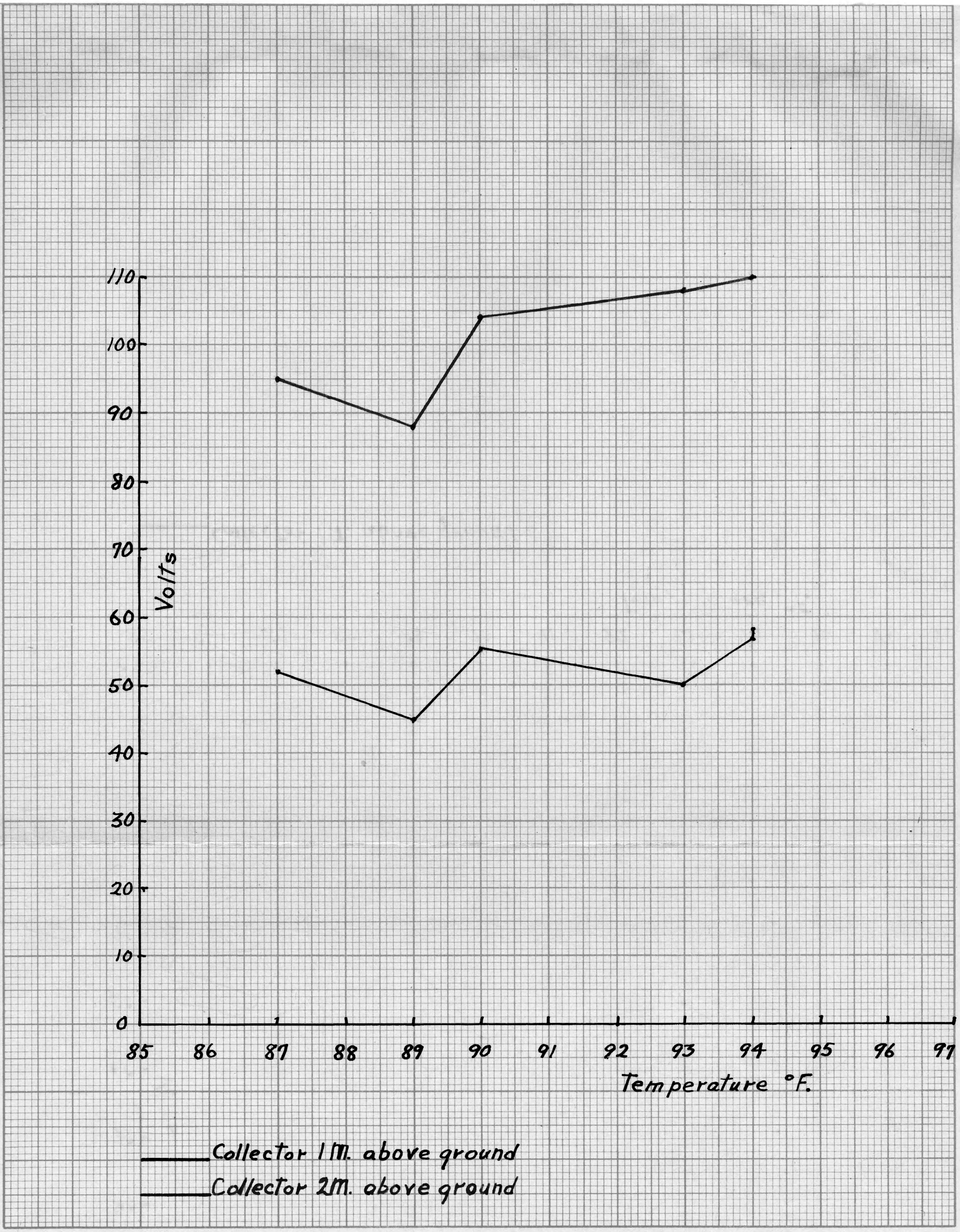

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Fig. 11. Variation of potential gradient with change in temperature on the four days, May 30, June 3, 19 and 23, 1933 10 A.M. - 4 P.M.

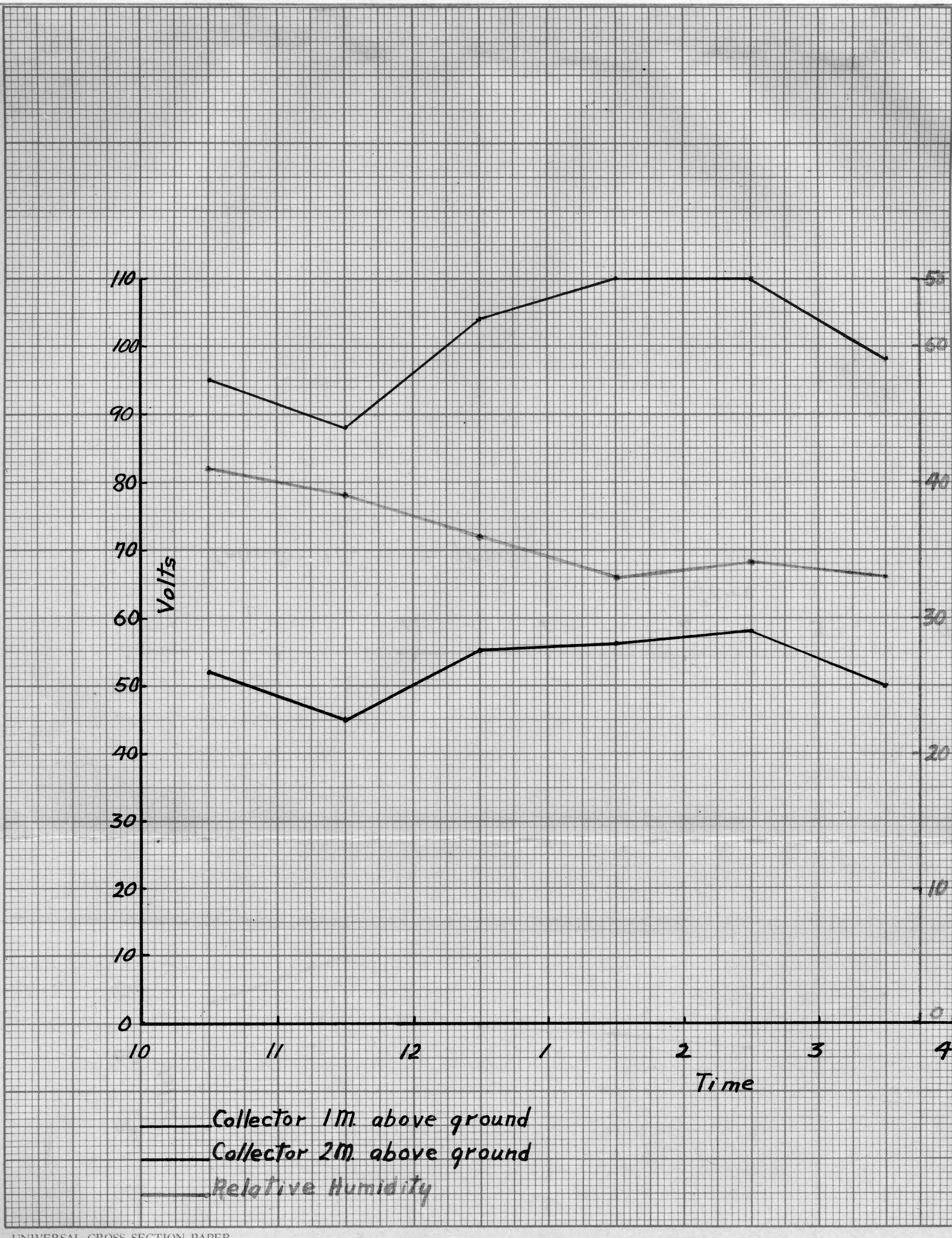

Fig. 12. Mean hourly variation of potential gradient and relative humidity for the four days, May 30, June 3, 19 and 23, 1933 10 A.M. - 4 P.M.

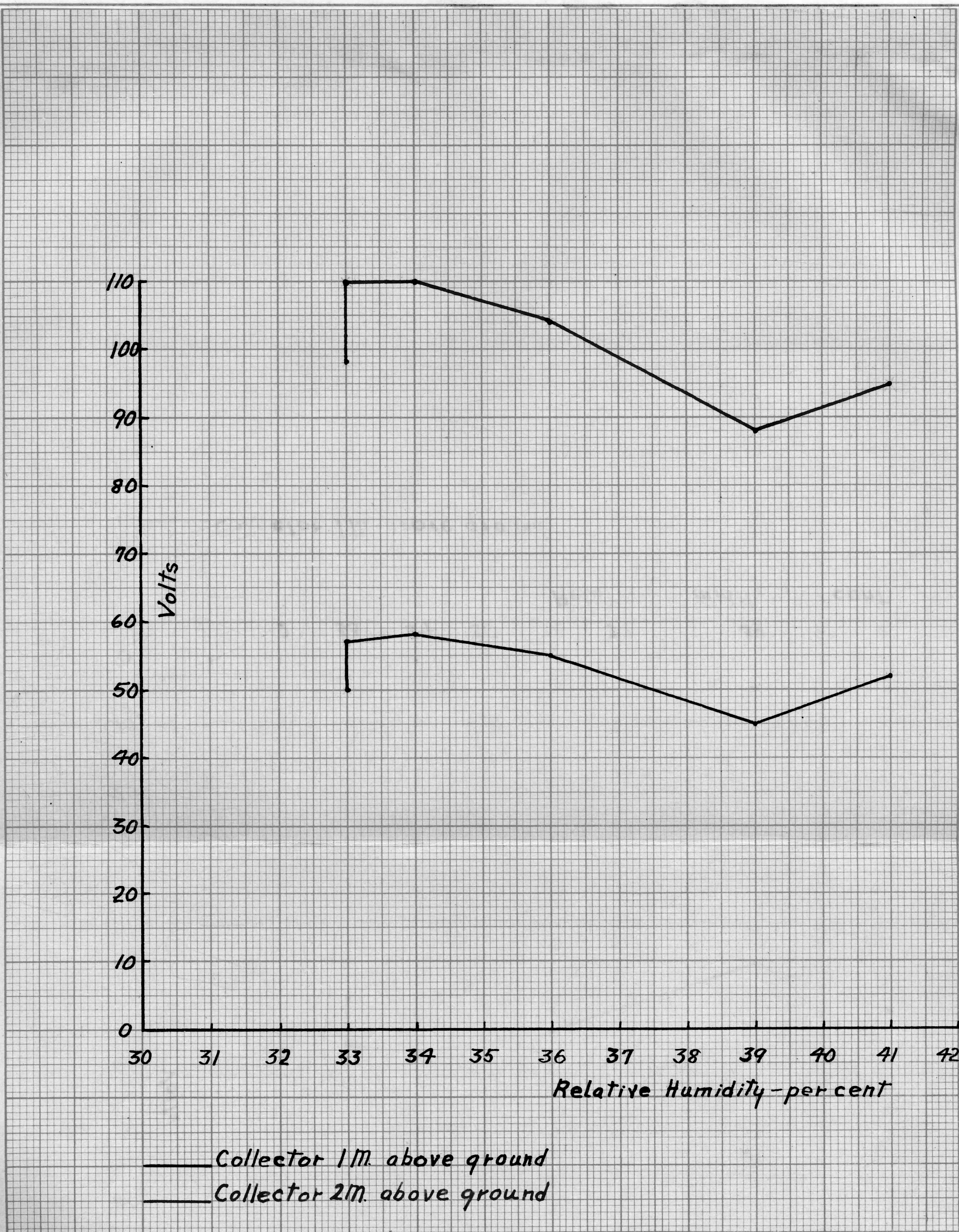

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Fig. 13. Variation of potential gradient with change in relative humidity for the four days, May 30, June 3, 19 and 23, 1933 10 A.M. - 4 P.M.

of curve that would be obtained if continuous photographic records were taken. It will be seen that at 10 o'clock the value of the potential gradient was about 60 volts per meter, and that from about 10:45 it oscillated about a mean value of 40 volts per meter. On the two occasions when it fell to zero value, the clouds referred to above, passed overhead.

The curves on Figures 4-8, showing the mean hourly variations of potential gradient, temperature and relative humidity for the single day, June 23, are very similar to the curves on Figures 9-13, which show the mean hourly variations of the above quantities for four days covering the same hours of the day; hence a discussion of the first group of curves is unnecessary.

Table 3 shows the mean hourly values of the potential gradient, temperature and relative humidity for the four days, May 30, June 3, 19 and 23, 10 A.M. - 4 P.M. These data are graphically represented on Figures 9-13.

An examination of the curves, Figure 9, will reveal the fact that the potential gradient as registered by the collector one meter above the ground, the black curve, fluctuates between the values 45 and 58 volts per meter, having a mean value of 53 volts per meter. The value of the potential gradient as shown by the collector two meters above the ground fluctuates between the limits 44 and 55 volts per meter, showing a mean of 51.5 volts per meter, differing from the lower wire by 1.5 volts. This discrepancy may be due to the fact that the surface of zero potential does not at all times coincide with the surface of the ground. Suppose, for example, the surface of zero potential were .1 meter below the surface of the ground. Under these conditions the collector suspended one meter above the ground would be 1.1 meters above the surface of zero potential, and the collector two meters above the ground would be 2.1 meters above the surface of zero potential. In other words, instead of being twice as high as the lower collector it would be only 1.9 times as high, and would be expected to read a little lower. The discrepancy is thus accounted for.

It may be of interest at this point to compare the value of the potential gradient as obtained by the writer with the value obtained by Wait (14) at Penalosa, Kansas, in August, 1929. The mean value for the hours 10 A.M. - 4 P.M. at Penalosa is 86 volts per meter as against 53 volts per meter at Manhattan. It should be remembered, however, that in order to be really comparable, sets of data at different stations should be taken at the same time. The general shape of the curves for the given hours of the day are strickingly similar for the two stations. The ground was very dry and the relative humidity low, about 36 per cent throughout the series, so on July 13, after several good rains, another brief set of observations was taken in order to see whether the change from dry to moist conditions would result in a change in the potential gradient. It was found that, with the relative humidity up to 53 per cent, and the ground thoroughly moist, the value of the potential gradient was now 90 volts per meter, bringing it more nearly in line with the value found at Penalosa.

Two curves have been drawn connecting potential gradient and temperature. In the curves on Figure 10 potential gradient and temperature have been plotted against time, and in Figure 11 potential gradient against temperature. Both curves seem to show a direct relationship between potential gradient and temperature. The relationship is undoubtedly more apparent than real. Other observers with more extensive data at their disposal have found that temperature is not a factor affecting the potential gradient to an appreciable extent.

The hourly mean values of potential gradient and relative humidity when plotted against each other, Fig. 12 and 13, give curves which would seem to indicate that the potential increases as the relative humidity decreases which is the inverse relation obtained by other observers. Here again, it must be said that the data obtained is insufficient to permit drawing definite conclusions.

A few remarks may be added here regarding the twenty-four hour run previously mentioned. The observations were started at 6 P.M. on June 2 and concluded the same hour on the next day. At the beginning the value of the potential gradient was about forty volts per meter; after about an hour and a half the potential began to diminish gradually, the value indicated by the lower collector diminishing much more rapidly than that of the upper collector, until at midnight the lower wire read zero, while the upper wire still showed thirty volts per meter. The lower wire then remained at zero, except for a few brief intervals, until 6 o'clock the next morning. The upper wire came to zero reading at 3:15 in the morning and remained at zero until 5 o'clock. During the time of these low values, the relative humidity ranged between seventy per cent and eighty-four per cent, reaching the maximum at 3:15 in the morning. Considerable insulation leak was observed when handling the switch, and these low values are undoubtedly due to insulation leaks caused by moisture collecting on the sulphur insulators. The fact that the lower wire came to zero value long before the upper wire did, would seem to bear out this conclusion. By referring to table 4 it will be noticed that the mean value of the potential gradient for this series is only about thirty-five volts per meter. This abnormally low value will be easily understood in the light of the above remarks. The sky was clear overhead although thin clouds could be seen near the horison. The average wind velocity was about seven miles per hour.

CONCLUSIONS

Table 4 gives a summary of the values of the potential gradient obtained on each day during this investigation. Approximately one thousand readings were taken and it may be stated that the potential gradient at Manhattan has a value of about forty-eight volts per meter, the low value possibly being due to the extremely dry conditions that prevailed during the time that observations were taken.

Table 4

Summary of results for the days and hours indicated.

Date	Time	P_1	P_2/h	Number of readings taken
May 29	2:15 - 6:15 P.M.	68	52	73
30	10:15 A.M.-4:50P.M	70	57	200
31	6:15 A.M.- 2:15 P.M.	43	39	240
June 2-3	24 hours	29	39	288
19	10 A.M. - 4 P.M.	47	47	72
23	10 A.M. - 4 P.M.	40	40	72
Means		50	46	945 - Total

From a consideration of the effects of topography as previously discussed, we may conclude that the error introduced by topographical distortions is not greater than ± five per cent.

The effects of atmospheric pollution must have been small. No high winds occurred during the whole series, consequently the air was remarkably free from dust. Probably the most important error introduced is the one due to insullation leaks but it is very difficult to determine its magnitude.

FURTHER INVESTIGATIONS

The observational data obtained during this investigation was necessarily limited on account of lack of time. In view of the large percentage of difference between the value of the potential gradient obtained by the writer and the value obtained by Wait at Penalosa, Kansas, it would seem desirable to obtain a more extended series of observations in order to check the results of this investigation.

The question whether atmospheric electricity is in any manner connected with changes in solar activity has again come to the front in recent years and is engaging the attention of several investigators. The amount of observational data which is continuous for a sun-spot cycle is indeed limited, which constitutes a serious handicap in these investigations. The need for more atmospheric-electric stations where continuous records can be obtained for a sun-spot cycle or longer is therefore evident. Such data of course could also be used in deducing an annual and a diurnal variation curve.

Since the present atmospheric-electric stations located either near the Atlantic or Pacific Coasts, from the point of view of geographical location, Manhattan, would seem to be an ideal place for a permanent station. The observatory should be equipped with instruments for obtaining continuous photographic records, because eye-readings can not be so completely representative of variations in the potential gradient as photographic records.

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