SMITHSONIAN MISCELLANEOUS COLLECTIONS

— 1077 —

## Hodgkins Fund

# EQUIPMENT AND WORK OF AN AERO-PHYSICAL OBSERVATORY

BY

ALEXANDER McADIE

CITY OF WASHINGTON
PUBLISHED BY THE SMITHSONIAN INSTITUTION
1897

# EQUIPMENT AND WORK OF AN AERO-PHYSICAL OBSERVATORY.

BY

ALEXANDER McADIE.

---

[Memoir submitted by Mr. McAdie in the Hodgkins Fund Prize Competition of the Smithsonian Institution in 1894, and awarded honorable mention, with a bronze medal.]

---

SUBJECT.

A. The known properties of atmospheric air considered in their relationships to research in every department of natural science, and the importance of a study of the atmosphere considered in view of these relationships.

B. The proper direction of future research in connection with the imperfections of our knowledge of atmospheric air, and the conditions of that knowledge with other sciences.

---

Two years ago the trustees of a New England university received plans and specifications for a laboratory. It was not to be a chemical laboratory nor a physical one, nor yet geological nor biological, but one to be devoted to investigation and research in aero-physics. During the present year one of the universities on the Pacific slope has established, or contemplates doing so, a chair of meteorology. At the time of the presentation of the plans and specifications referred to above, it was pointed out that, with the possible exception of the department of mathematics, every department of science then represented at that university would be directly served and greatly benefited by the work of this high-class aero-physical laboratory. The chemist, the physiologist, the biologist, botanist, and physicist must have authoritative knowledge of the conditions of external air pressure, temperature, humidity, and atmidometry (if the word may be used) at the time of their experimentation if true results are to be obtained.

And back of research and investigation always there looms up the application of knowledge to the needs and wants of the community. In aero-physics there exists without doubt a demand for standard records and exact determinations. Even as these lines are written the demand for standard rainfall, temperature, wind, pressure, sunshine, and cloudiness records is greater than the skill and industry of the meteorologist, as he is now equipped, can meet. That the "nature and properties of atmospheric air in connection with the welfare of man" is a topic crying aloud for recognition let the vexed questions arising in our daily intercourse answer. The courts call constantly for information, and authenticated records are admitted as evidence. Intelligent inquiry for data not available confronts the meteorologist daily. The engineer, be he civil, mining, electrical, or sanitary, knocks with increasing frequency at the door of the aero-physicist. The physician's inquiries are manifold. Averages, extremes, and rates of change affect our well-being; and yet when he receives all the data now available he receives but a meager portion. With reference to the origin and spread of disease and in all questions of pathogenesis and metabolism, we are but poorly off in knowledge of the relation to these of either the chemical or physical properties of atmospheric air. Rayleigh and Ramsay have just shown in their work on nitrogen how little we know of that very gas which by volume in 100 parts of our atmosphere would be 79.19. With the discovery of argon our conception of the part played by nitrogen in organic life must undergo change. This discovery, in the words of a great chemist, Sir Henry Roscoe, is one "of the greatest possible interest and importance, and of special significance as being one brought about by the application of exact quantitative experiment to the elucidation of the problem of the chemical constitution of our planet."

Pass now to a description of this proposed aerö-physical laboratory and it is perhaps but proper to say that at least two observatory-laboratories somewhat approximate the equipment here set forth.

Barometry.

- Standard barometers—Wild-Fuess, Fortin, or Kew.
- Multiplying barographs—Richard, Marvin, or Draper.
- Aneroid, Redier or improved Hicks.
- Statoscope for minute fluctuations of pressure;—of especial value during thunder-storms and gusts.
- Sundell normal barometer.
- Telebarometers, distant from each other not less than 1,000 feet in a horizontal direction and 500 feet in a vertical direction. This implies that the laboratory must be situated on the summit of a hill or mountain, with base stations. Buchan, in his résumé of the work done at Ben Nevis, intimates that some very important relations are thus discoverable.

THERMOMETRY AND HYGROMETRY.

Standard types of thermometers—exposed, wet-bulb, maximum and minimum, water and soil.

Thermographs and self-registering psychrometers.

Assmann aspiration psychrometer.

Telethermographs and telehygrographs.

INSOLATION.

Actinometer (Schwolsen).

Langley's bolometer, with appropriate galvanometers for the exploration and mapping of the solar spectrum, particularly the infrared portion.

Photographic records of the more prominent absorption lines due to aqueous vapor in the atmosphere, and comparison, after proper scale determination, with the intensity of standard solar lines, with the ultimate aim of ascertaining this distribution of vapor in the atmosphere at various altitudes and variations therefrom.

Spectroheliograph. A good 12 or 14 inch photographic objective for investigating the relations of solar spots, faculæ and prominences.

NEPHOSCOPY AND PLUVIOMETRY.

Sunshine recorders of various types.

Nephoscopes and Pole star recorders.

Rain gauges and evaporometers.

ATMIDOMETRY.

Barus's device for showing colors of cloudy condensation.

Aitken's dust-counter or coniscope.

The determination of the amount of haze or smoke present in the atmosphere is now quite neglected in meteorology, although a matter of very considerable importance to health. We should have daily records of the relative purity of the atmosphere.

ANEMOMETRY.

Anemoscopes.

Anemo-cinemograph—an instrument showing the varying force exerted by the wind, superior to the old form of anemograph; and yet some further improvement looking to a fuller recognition of what has been termed "the internal work of the wind" is desirable.

Helicoid anemometer.

Clino-anemometer, or instrument for registering currents not horizontal.

Wind pressure gauge and suction anemometer.

Thermodynamics and Chemistry.

Apparatus might be devised which would give graphically the thermodynamic conditions of the atmosphere. The volume, pressure, temperature, and density of the air being known, we ought to be able to follow the isotherms and adiabatics through the varying conditions in cyclone and anti-cyclone at all levels. Thus Hertz (Graphische Methode zur Bestimmung der Adiabatischen Zustandänderungen feuchter Luft, Meteor. Zeits., 1884) has given the adiabatics for the dry, rain, and hail stadia, and it is practicable to follow a given air mass through the varying thermodynamic conditions.

Electrometry.

Proper apparatus for measurements in atmospheric electricity.

Mascart-Kelvin electrometers for the determination of the potential of the air. The type of voltmeter known as the multiple quadrant electrometer, or substantially Lord Kelvin's air leyden, should be installed with an automatic register for continuous records of the electrification of the air.

Elster and Geitel's apparatus, modified, for records of the air "leakage" of electrical charge under the influence of ultra-violet light.

Brontometer, for use in the study of the strains and stresses in air between highly electrified clouds or cloud and earth. The name brontometer is used, but some more appropriate type of instrument than the present is desired. It now gives the time of each lightning flash, the duration of thunder, the changes in direction and force of the wind, in temperature, humidity, and barometric pressure during a thunder-storm; but there is wanting the photographic auxiliaries to delineate the character of each discharge. The true direction in space and the dimensions of the discharge are determinable by such means. The potential fluctuations added to such data will enable us to study the strains and ruptures in the atmosphere after the thunder-storm as completely as a plate of fractured armor can be studied after a test.

## Physiology and Biology.

The known properties of atmospheric air are clearly of great importance in all physiological and biological research. In the latter, atmospheric environment must be an effective factor in the variation of species, and in the former, at the very outset, do we not meet an intimate relation between the irritability of nerve and muscle with atmospheric conditions?

How important to know the atmospheric conditions as influencing exhilaration and fatigue. The so-called "sensible" temperature, for example, enables one to live in the temperatures of the Southwest in summer and renders temperatures lower by twenty degrees elsewhere unbearable.

In such a laboratory, then, trained intellects studying the properties of atmospheric air, would, we firmly believe, influence research in every department of applied science. In agriculture the value is apparent; in economics, history, hygiene, botany, geology, and biology, questions now unanswered would be disposed of. In that much-dreamed-of consummation, the conquest of the air, when transportation shall be by air-ships and communication by air-runners or disturbances of the electrified air, the contributions to knowledge from such a laboratory would be incessant and without price. Aye, in directions now unthought of, the aero-physicist would push onward in the great region now unexplored. When the Berlin Academy, in 1879, offered a prize for the experimental determination of a relation between electromagnetic forces and the dielectric polarization of insulators, perhaps no one—certainly neither Helmholtz nor his assistant, whose attention he directed to the matter—foresaw more than certain experimental determinations. Hertz took his problem as he received it. We have his own words that he started out to prove that changes of dielectric polarization in non-conductors produced the same electromagnetic forces as do currents which are equivalent to them, and that electromagnetic as well as electrostatic forces are able to produce dielectric polarizations; and yet, further, that in all these respects air and empty space behave like all other dielectrics. "I saw no way," he says (see "Electric Waves"), "of testing the first and second for air, but both would be proved simultaneously if one could succeed in demonstrating for air a finite rate of propagation and waves." Let us exult in Hertz as the first aero-physicist and join Lord Kelvin in his triumphant declaration, when referring to waves of electric force, that "the processes in air represent on a million fold larger scale the same processes which go on in the neighborhood of a Fresnel mirror or between the glass plates used for exhibiting Newton's rings."

The direction in which the demand for immediate application of our knowledge of aero-physics is greatest is in connection with the tides and fluxes of the aerial ocean in which we live, the storms and currents of the atmosphere. There is a popular impression that forecasting weather conditions is in a high degree a matter of scientific procedure. Much that is scientific in character has been done, it is true; but, without disparaging such work, it remains none the less true (and we but echo the sentiments of those professionally engaged in forecasting) that the present condition of our knowledge is quite unsatisfactory. Newton's boy playing upon the seashore and picking up here and there a pebble while the broad ocean of truth lay all unexplored before him may be not unfairly compared with the forecaster of to-day. One of the proper directions of future research in connection with our knowledge of atmospheric air, then, is the prevision of the weather. To foregauge the changes in the atmosphere is not the least promising direction for future research in connection with the imperfections of our knowledge of atmospheric air. We speak not of "controlling" the weather. The making of rain, of warm and cold waves, the maintenance of equable temperatures are, despite the present apparent extravagance of such aspirations, serious and legitimate fields for the application of science; but the nearer problem, that of accurately forecasting weather changes, has already been carried to a certain degree of success, and we may well therefore confine our study to methods available for the improvement of weather prediction.

This, then, is the problem before us, viz., the successful scientific forecasting of atmospheric conditions. In no other direction would the work of the aero-physical laboratory, to which reference has been made, be so pronounced; and carried from the present short period to periods of weeks or months, what branch of applied science will be found to exert so great an influence upon the welfare of man?

We shall present first a careful analysis of methods in use—*i. e.*, a study in detail of the synoptic weather map, discussing the sources of its unquestioned strength and its elements of weakness, and then consider methods as yet untried, but which have scientific indorsement and seem to be applicable to the question before us.

The principle underlying the synoptic weather map of every weather service is simultaneity of observation. A forecaster has before him a bird's-eye view, as it were, of the conditions existing at a given moment. After an experience of nearly twenty-five years, when the question is asked, "Has the synoptic map realized the expectations of meteorologists and justified the expense of its existence?" the answer is, "Yes." But if the further question is asked, "Is the forecaster of to-day as far in advance of the forecaster of 1870 as might reasonably be inferred from the lapse of time?" the response is halting and uncertain. The experience of the past ten years would seem to indicate that we are close to exhausting the capabilities of the weather map in its present form. The introduction of modern inventions may help some, for we recall that it was the telegraph which made the map possible, and the telautograph, for example, may enable us to get continuous records in place of the fragmentary ones now in use; but not until we are able to reach out from the earth surface and study *in situ* air stratification and record simultaneous changes at all levels will the great advance in forecasting be accomplished. The exploration of the upper air by "aerodromoi" means the determination of abnormal temperature and rainfall relations at various heights.

*Cloudy Condensation.*—Perhaps even more than temperature, rain is the element of least certainty in forecasting. How, then, can we improve the methods in use for foretelling the likelihood and determining the causes of rain? Of the physical processes of condensation we know much and at the same time little. Studies of condensation from fusion, vaporization, and solution, and particularly on the passage from vapor to liquid in the free air and the control of the conditions determining such passage, should be undertaken. With our present rather crude outfits some work might be done in the nature of preliminary surveys of cloud land. At present cloud maps are of such indefiniteness that but limited use is made of them in forecasting. Granted that cloud types and motions have little of the significance that some enthusiastic nephoscopists claim for them, the fact nevertheless remains that clouds from their very office are significant exponents of air-strata conditions. Hildebrandsson long ago showed that the upper currents move along somewhat parallel to the lower currents up to a certain height, and then change their motion, and we are all familiar with Clement Ley's law, "upper clouds have a distinct centrifugal tendency over areas of low pressure, and a centripetal over those of high." If we knew more about cloud motion and stratification, forecasting would be more certain.

To illustrate in a rough way the importance of cloud motion, let us take the date August 27, 1893, a time when telegraphic reports from Florida and the southeastern seaboard were interrupted. It is evident that if no reports can be obtained by telegraph, the synoptic map as at present used must fail. Such was the case during the memorable storm of March 11–13, 1888—the so-called "blizzard." But in the storm of 1893 it so happened that the most destructive storm of the year was heading in towards the Florida coast. No reports were to be had from Florida, high wind having blown down the poles. What, then, was the forecaster to do? The motions of the upper clouds at Lynchburg, Chattanooga, Knoxville, and Norfolk plainly indicated the position of the "low." If, with such crude and undeveloped observations, there was so much of value in cloud-work, with how much more definiteness could this storm have been located had the motions of the upper clouds at various points been instrumental determinations. One much-needed advance in forecast work is the use of nephoscopes, and it is passing strange that our weather services have not long ago discarded their methods of eye observation. Color, form, and relative motion appeal so strongly to the imagination that even a practiced observer will misinterpret the cloud.

Observations with high-order nephoscopes would be valuable in throwing light on that which is so essential—a knowledge of the true motion of the air. The convectional theory of cyclonic formation, of which Ferrel was the great advocate, has in its favor all that we at present know of cloud motion. But we know so little. The so-called descensional theory finds, on the other hand, in the general upper circulation the initiative impulse for storm formation. From this point of view, cyclones and anti-cyclones are but great double vortex knots in the general air stream. The upper current works down through the anti-cyclone and in a reversed twist out through the cyclone; and it is evident that cloud motion, had we but the means of observing it properly, would give weighty evidence? Similarly the condensation conditions in free air must be studied. We may get an inkling of the size of the water globules by the colors of cloudy condensation. The Newtonian interference colors might be made use of in some modified form of Michelson's "interferential refractometer" to get the dimensions of the condensing particles. The increase and decrease of size might be determined and variations interpreted as favoring or not favoring condensations. Every line of research tending to give knowledge of the extent and intensity of conditions favoring condensation should be encouraged by weather services. At present the forecaster lacks information worthy of acceptance concerning the amount of vapor overhead at different levels; nor has he any clew whatever as to impending motions of the same, ascensional or descensional. Perhaps the question of the production of artificial rain will force meteorologists to develop our knowledge in this direction. Storm motion is to be regarded in the light of a key unlocking an appropriately unstable condition of atmosphere. "Dry" storm areas prove beyond doubt that something beside storm mechanism is necessary for precipitation. The energy of a storm and its rate of motion would mean vastly more to the forecaster if he had at his command the seasonal vapor conditions for all elevations. Theoretically the claim of the rain-maker has this much truth to it, that in some districts, at certain times, not only the smoke of a small brush fire, but the unfolding of an umbrella, might suffice to initiate an air motion which would result in more or less precipitation. Furthermore, the forecaster must always clearly distinguish between conditions favoring storm progression and the likelihood of storm formation. Some of the factors operative in storm formation and which the forecaster should be cognizant of are: extent of in-draught of warm moist air and counter-draft of cold dry air; relative instability of the air; topography as affecting air drainage, and the vapor values at different elevations. It is very important that the values of the absorption lines due to aqueous vapor be determined. Becker, in the "Trans. Roy. Soc. Edin.," XXXVI, has mapped 928 lines of this character. He divides the aqueous lines into three groups somewhat as follows:

Wave-lengths, 6,020 to 5,666, comprising about 678 lines.
" 5,530 " 5,386, " " 106 "
" 5,111 " 4,981, " " 116 "

But this list can undoubtedly be extended, and particularly in the infra-red portion of the spectrum, where we naturally would expect to find the most marked atmospheric effects. We suggest, then, as one of the most fruitful directions for research the exploration of the solar spectrum with the view of determining the vapor present at different levels under varying conditions and the application of the knowledge so obtained to forecasting weather changes. A hint from Buchan, in his résumé of the work done at Ben Nevis, a high-level meteorological observatory, should not be overlooked. Although discussing temperatures, his remarks will apply with equal force to vapor values: "The departures from the normals, especially inversions and extraordinary rapid rates of diminution with height, are intimately connected with cyclones . . . and form data as valuable as they are unique in forecasting storms." We would urge, too, the mathematical discussion of each storm, particularly with respect to storm energy and motion. The storm of August 26, 27, 28, 1893, sometimes known as the Sea Islands storm, from the great damage done along the Carolina coast is one that will always draw the attention of the meteorologist. The story of the origin of this storm, its path, the terrors of the accompanying rise of the waters, whereby nearly twelve hundred lives were lost, has been graphically given in the popular magazines of the day. We propose to test with it some equations given by Maxwell Hall (Jamaica Meteor. Obs., vol. I) for determining storm approach when observations are available for one side of the storm only.

Other things being equal, we may assume that the storm will be retarded by—

1. Opposing conditions such as obstructive "high"—that is, a slow-moving, inert anti-cyclone.
2. Decrease of storm energy or weakening in the formative factors.
3. When the slope of the diurnal and seasonal curves of pressure (and the reverse for temperature) is opposed in direction to the gradient caused by the storm.

Conversely, we may look for an increase of storm energy with persistence of conditions favoring storm development.

If $p$ = pressure reduced and corrected for diurnal variation,

$C$ = twelve-hour change,

$v$ = velocity of wind in miles per hour,

$r$ = distance from the centre of cyclone,

$\frac{dp}{dt}$ = rate of fall of pressure per hour,

$\frac{dp}{dr}$ = gradient or fall per mile toward the centre,

$$\frac{\frac{dp}{dt}}{\frac{dp}{dr}} = \frac{\text{rate of fall}}{\text{gradient}} = \frac{dr}{dt} = \text{rate of approach,}$$

as a first approximation for the time of arrival, divide the distance by the rate of approach. These values are given in column "A," in the table below.

$$A = \frac{r}{\frac{dr}{dt}} \text{ or } \frac{rdt}{dr}. \qquad f = 1 \div (dr \div dt).$$

It must be pointed out that in a calculation of this kind we are restricted to the use of such data as are available for the forecaster at a particular time. We think that the following, which could have been obtained at the times indicated, would have been serviceable in forecasting this storm, and particularly the values which are underscored as indicating the probable path and duration of the storm :

*Approach of Storm of August 25, 26, 27, 28, 1893.*

| Date. | Station. | Pressure. | $C$ | $v$ | $r$ | $\frac{dp}{dt}$ | $\frac{dp}{dr}$ | $A$ | $f$ |
|---|---|---|---|---|---|---|---|---|---|
| Aug. 26, 1893, 8 a. m. | Titusville. .. | 29.90 | —.06 | 22 | 250 | .004 | .001 | 30 | .20 |
| | Jupiter....... | 29.80 | —.10 | 24 | 160 | .008 | .014 | 24 | .15 |
| Aug. 27, 1893, 8 a. m. | Savannah..... | 29.78 | —.16 | 20 | 200 | .012 | .002 | 30 | .15 |
| | Charleston.... | 29.84 | —.12 | 24 | 230 | .01 | .002 | 50 | .20 |
| | Jacksonville .. | 29.62 | —.24 | 20 | 120 | .02 | .003 | 20 | .17 |
| | Titusville..... | 29.34 | —.38 | 40 | —80 | .036 | .003 | —8 | .30 |
| Aug. 28, 1893, 8 a. m. | Lynchburg.... | 29.84 | —.12 | 8 | 230 | .01 | .002 | 70 | .25 |
| | Raleigh. ..... | 29.64 | —.26 | 22 | 220 | .03 | .002 | 25 | .12 |
| | Charlotte..... | 29.30 | —.54 | 24 | 100 | .014 | .003 | 6 | .8 |
| | Augusta...... | 28.96 | —.72 | 26 | —20 | .06 | .01 | —4 | .... |

A line drawn through the underscored values for the dates in question will be found to almost coincide with the path of the storm. Minus values indicate the retrogression of the disturbance.

Suppose further, however, that, starting with the fundamental equation $pv = RT$, we were able to follow any given air wave as it is propagated in a manner similar to that in which an ordinary sound wave is followed. Lord Rayleigh ("On the Vibrations of an Atmosphere," Phil. Mag., Feb., 1890) has given a numerical example of the high degree of rarefaction necessary before there is a change of sign for a period of one hour. In C. G. S. measure, $n = \frac{2\pi}{3600}$ and "$a$" (the velocity of sound) $= 33 \times 10^4$, $g = 981$; then the ratio of the density at a given height to the density at the ground comes out 1/290. This, of course, is for an upward wave; but for the case of "a swaying of the atmosphere from one side of the earth to the other" Rayleigh deduces a period of 23.8 hours. He remarks, however, that the suitability of the value of "$a$" is very doubtful, and, further, that the suppositions of his paper are inconsistent with the use of Laplace's correction to Newton's theory of sound propagation. Moreover, can the heat and cold present in atmospheric vibrations be supposed to remain constant? But the near approach of this period to 24 hours he considers to be of more than passing interest and possibly connected with the diurnal and semi-diurnal variations of the barometer.

Now, the forecaster has to deal with a succession of atmospheric waves, and it is just the gain or loss of heat accompanying the propagation of the slower waves that he attempts to forecast. Therefore we think it to be of prime importance to introduce into our forecast work as far as possible numerical values for atmospheric vibrations.

## Atmospheric Electricity.

We have thus far discussed the known properties of atmospheric air chiefly in connection with aqueous vapor. There remains another equally important line of research intimately related to the vapor conditions and likewise of great importance in weather prevision, viz., atmospheric electricity.

At the outset we advocate the introduction of that unstable and seemingly lawless element, the electrical potential of the atmosphere, on the synoptic weather chart. To the graphic representation of air pressure, temperature, and in a crude way, air motion, let us add, although it does seem unpromising, the electrical potential, corrected for temperature, elevation, quantity of vapor present (see further on Exner's experiments and the very recent paper of Kelvin on the Subtraction of Vapor from Air and the Electrification). The potential charted for any given moment upon the synoptic map will give, in the general electrification of the lower air strata, significant equipotential lines and areas. The time is ripe for such a preliminary survey, or, as Sir William Thomson once called it, "electro-geodesy"—in brief, an extended synchronous survey of the potential of the lower air.

We may begin our plea for such work by a reference to the work of Professor Franz Exner, of Vienna. With praiseworthy persistency he has determined the potential values in all localities accessible to him, and with some approximation the potential gradients at various elevations. The work of Elster and Geitel, especially their later work, constituting what may be termed researches in electrical actinometry, is a natural outcome of and supplement to Exner's work. As we shall see, Exner's determinations were all made with portable electroscopes or electrometers, and while the instruments used by him differ in design from those (in our opinion preferable) used in the United States, Great Britain, and France, the scope and method of work have been practically similar. The differences in results are mainly of degree, Exner having carried his work further. The aim throughout has been the exploration of the electrostatic field of the earth. In the experiments of Elster and Geitel at Wolfenbuttel (see "Sitz. Akad. Wien.," June, 1892, and subsequently; also "Nature," March, 1893), the direction of research has been that of the relation of the potential values to the intensity of ultra-violet radiation. This we see at a glance opens up a new field of investigation in the discovery that ultra-violet light accelerates the dissipation of an electrical charge, and there is no telling what further developments may come in both electrometry and actinometry.

S. V. Arrhenius ("Meteor. Zeits.," vol. v, p. 297, and "Phil. Mag.," July, 1889) touches upon the influence of solar radiation on the electrical phenomena of the earth's atmosphere, and shows that when the air was irradiated by ultra-violet light it conducted like an electrolyte. We recall that Hertz found in his experiments that the receiver required continual readjustment, either because of the shaking or the slight burning of the points, and that ultra-violet light falling on the "vibrator" prevented its proper action, the sparking in the "resonator" ceasing or becoming feeble. This discharging action seemed to be particularly noticeable when the violet light fell upon negatively electrified points. Elster and Geitel have shown ("Sitz. d. K. Akad. der Wissen. Wien.," 99 Band, x heft, s. 1011) that a body with a negative charge is discharged under the influence of the above-described radiation more rapidly than a body charged positively. For example:

| | Rate of loss when positively electrified. | Rate of loss when negatively electrified. |
|---|---|---|
| Rusty iron | 16 | 24 |
| Polished iron | 16 | 31 |
| Charcoal | 11 | 25 |
| Mica | 12 | 26 |

The above results show clearly a more rapid loss of the negative charge.

Professor Oliver Lodge, in a lecture upon the work of Hertz, delivered at the Royal Institution June 1, 1894, used the following language:

"While Hertz was observing sparks such as these, the primary or exciting spark and the secondary or excited one, he observed as a bye-issue that the secondary spark occurred more easily if the light from the primary fell on its knobs. He examined this new influence of light in many ways, and showed that although spark light and electric brush light were peculiarly effective, any source of light that gave very ultra-violet rays produced the same result. Wiedemann and Ebert and a number of experimenters have repeated and extended this discovery, proving that it is the cathode knob on which illumination takes effect; and Hallwachs made the important observation, which Righi, Stoletow, Braly, and others have extended, that a freshly polished zinc or other oxidizable surface, if charged negatively, is gradually discharged by ultra-violet light."

Lodge hints in his lecture of the possible great value of these relations in atmospheric electricity.

Collecting the observations of the potential fall in the case of negatively electrified bodies exposed to sunlight, Elster and Geitel have tabulated the values of the mean daily potential, the temperature, and the vapor pressure. These are given on the following page. Would it not be a very happy and profitable research to undertake in the United States a similar series of experiments confirming and extending the results now at hand? Particularly at Pike's Peak and at Mount Washington could such determinations be effectively undertaken. At the former station the range of vapor pressure is so large that the curves now known could be extended. A physical law expressing the relation of the potential and the intensity of the more refrangible rays would perhaps be the outcome.

*Elster and Geitels Potential-vapor Values.*

| Mean. | $\frac{dv}{dn}$ | $v$ | Mean vapor pressure in mm. | Mean temperature in $C°$. |
|---|---|---|---|---|
| 6 observations | 502 | 54 | 1.4 | —11.8 |
| 6 " | 430 | 59 | 1.7 | —10.1 |
| 14 " | 400 | 141 | 2.3 | — 6.4 |
| 15 " | 318 | 150 | 3.5 | — 0.8 |
| 23 " | 252 | 257 | 4.4 | 4.7 |
| 8 " | 137 | 91 | 5.5 | 10.0 |
| 11 " | 184 | 120 | 6.4 | 9.9 |
| 16 " | 148 | 169 | 7.5 | 12.6 |
| 13 " | 112 | 158 | 8.4 | 15.1 |
| 14 " | 115 | 135 | 9.4 | 16.8 |
| 7 " | 118 | 76 | 10.7 | 19.4 |
| 5 " | 121 | 54 | 13.8 | 21.8 |

We can get at the relation of the potential values and the quantity of vapor present in the following way:

The weight of aqueous vapor in a cubic metre of saturated air is the product of the weight of a cubic metre of dry air at $0°$ $C$, pressure 760 mm. and the density of the aqueous vapor, and the pressure of aqueous vapor in saturated air, all divided by 1 plus the temperature correction.

$W = \frac{ad}{1 + \alpha t} \frac{F}{760}$, where $a = 1.29278$ $kg$, $d = 0.6221$, and $\alpha = 0.003667$

the weight of vapor then is $0.622 \frac{1.29278}{1 + .003667\, t}$.

| | Observed $v$. | Estimated $v$. |
|---|---|---|
| 1.6 | 502 | 469 |
| 1.9 | 430 | 442 |
| 2.5 | 400 | 364 |
| 3.7 | 318 | 268 |
| 4.6 | 252 | 224 |
| 5.6 | 137 | 189 |
| 6.5 | 184 | 166 |
| 7.6 | 148 | 145 |
| 8.4 | 112 | 133 |
| 9.4 | 115 | 119 |
| 10.6 | 118 | 107 |
| 13.5 | 121 | 85 |

And thus, as the authors point out, with the exception of the vapor group 5.5 mm., the potential curve runs inversely with the vapor pressure, and the observed values and the estimated values agree fairly well up to a certain point. When the number of grammes of moisture in a cubic metre of air at the earth's surface exceeds 8, however, the agreement no longer holds. (See diagram, page 18.)

The aim of all this, as we shall see in discussing Exner's observations, is the determination of a relation between the potential gradient and the humidity and the construction of apparatus in the nature of an electro-hygroscope. One advantage this new method might possess over spectroscopic methods is at times of cloud formation. Cloudy condensation we know limits rain-band investigation, but the electro-hygroscope would in all probability be serviceable with visible as well as invisible vapor. Indeed, it is not certain but that the potential values would be more strongly marked at such times.

We must give now as briefly as possible the results of the observations of Elster and Geitel on the Hoher Sonnblick, some 10,168 feet above sea level, and at its low-level station, Kolm-Saigurn. As we said above, such observations, repeated at Pike's Peak and other high-level stations in the United States, would certainly widen the horizon in aero-physical work. Harvard College Observatory has published in its "Annals" the meteorological observations made at Pike's Peak for a given number of years. If one will turn to pages 459, 460, and on, he will find such observations as the following:

" . . . faint auroral streamers and beneath them the usual sheet lightning flashed incessantly. . . . "

" . . . at night the summit capped by a cloud so small that the observer at the base could hardly see it, and was frequently lit up by flashes of lightning. . . . "

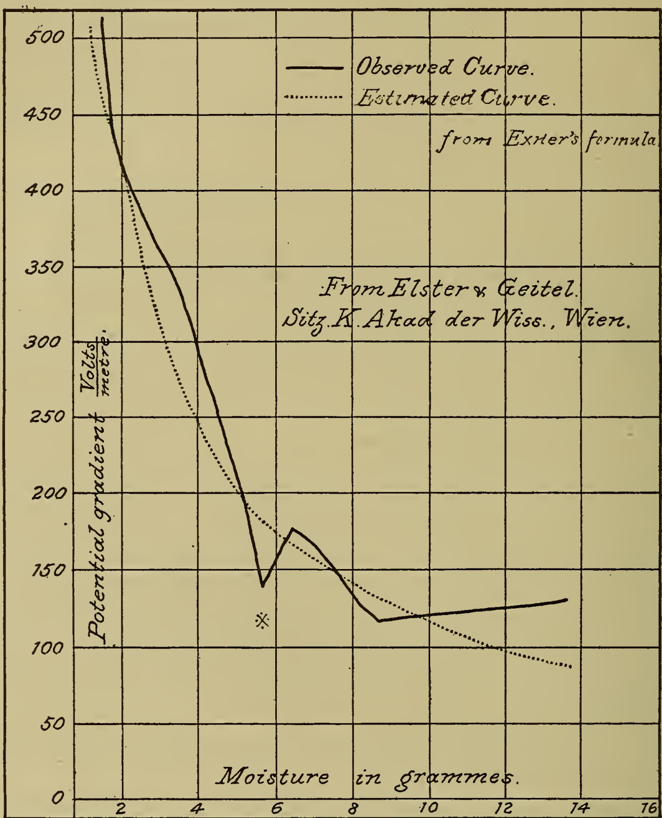
" . . . heavy snow, with thunder and lightning. . . . "

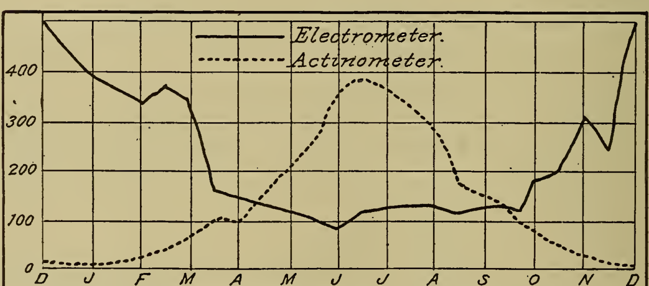
" . . . electricity increased and decreased with the fall of hail—a fact noticed in all hail-storms at the station. . . . "

In few ways, therefore, do we think that investigation under the conditions of the Hodgkins bequest could be more effectively undertaken than in investigation of the electrical condition of the atmosphere at some such station as Pike's Peak.

The Sonnblick observers found—

1. " The intensity of the most refrangible rays of the solar spectrum, as measured by the discharging action on negatively electrified surfaces of amalgamated zinc, increases with the height above ground in such a manner that at a height of 3,100 metres it is twice as great as on ordinary level ground."




Simultaneous Actinometer and Electrometer yearly Curves

Elster & Geitel.

2. " Notwithstanding this increase in the power of discharge of light, we [Elster and Geitel] did not succeed in establishing with certainty any new actinometrically active surface. Even perfectly freshly fallen snow as well as dry rock were not appreciably discharged by light."

3. " Waterfalls can produce negative falls of potential in a valley and even to considerable heights (1,600 feet), and it may be assumed that this remarkable phenomenon is not produced by friction, but by the influence of the normal positive fall of potential on the finer pulverulent water which detaches itself from the large masses of water; and it may perhaps be assumed that in a rain-cloud the process of self-induction increases to high values the originally feeble negative charges of a layer of air dust at the foot of a fall."

4. " In July, 1890, on three days, which were almost cloudless until 1 p. m., the normal positive fall of potential on the top of the Sonnblick was apparently constant. The morning maximum, which in the Plain and Alpine valleys occurs with great regularity between 7 a. m. and 9 p. m., was not observed at a height of 10,168 feet."

5. " Before the outburst of the storms which we observed on the 16th, 18th, and 20th of July, the positive fall of potential within the cloud, which sent only a small quantity of rain, went slowly down to the value zero and remained there for a long time."

6. " In storm clouds the atmospheric electricity usually changes its sign after a discharge of lightning, as with storms on the plain."

7. " Saint Elmo's fire was found to be a constant accompaniment of storms. It was not found that negative Saint Elmo's fire was more infrequent than positive."

8. " The observation that negative Saint Elmo's fire follows bluish lightning and positive follows reddish lightning was frequently confirmed by us. The direction, then, of the electrical current which traverses the atmosphere in the form of lightning appears to have an influence on the color of the lightning."

All of the above results may be found in the " Phil. Mag.," May, 1891, and " Wien. Berichte," November, 1890. We shall now proceed to comment upon them.

It is of some interest to know whether our mountain peaks, taking as they must a negative electrification from the earth, are discharged more rapidly when illuminated by the more refrangible rays. Since the above experiments were made the entire question of the capacity of the air and the disposition of a charge has been brought forward for discussion by Kelvin's paper on the subtraction of vapor from air and the consequent change in electrification. J. J. Thomson has shown in his recent paper on the " Electricity of Drops " that a small amount of impure matter in water is enough to produce a marked change in the electrification, and that therefore no study of atmospheric electricity will be complete which does not take into account the degree of purity. Kelvin from laboratory experiments (see paper read before British Association at Oxford; also "Nature," July 19, 1894) concludes that the air does not retain a negative electrification so long as it retains a positive. Kelvin says, "the equilibrium of electrified air within a space enclosed by a fixed bounding surface of conducting material presents an interesting illustration of elementary hydrostatic principles. The condition to be fulfilled is simply that surfaces of equal electric 'volume density' are surfaces of equal potential, if we assume that the material density of the air at given temperature and pressure is not altered by electrification. This assumption we temporarily make for want of knowledge; but it is quite possible that experiment will prove that it is not accurately true." "On the supposition of electric density uniform throughout the spherical enclosure, each cubic centimetre of air experiences an electrostatic force toward the boundary in simple proportion to the distance from the centre and amounting at the boundary to nearly 10 per cent. of the force of gravity upon it; . . . " "Under natural conditions with great density there must be an important ponderomotive force quite comparable in magnitude with that due to difference of temperature." . . . "Negatively electrified air over negatively electrified ground with non-electrified air above it in an absolute calm would be in unstable equilibrium."

Lord Kelvin gives an estimate of the density and force in a given enclosure.

Let $V$ equal the potential indicated by the water-dropper; $a$ equals the radius of the spherical hollow (in which the air was); $\rho$ equals electrical density of air at distance $r$ from center; then from—

$$V = 4\pi \int_o^a \left( \frac{r^2}{r} - \frac{r^2}{a} \right) dr$$

if $\rho$ is constant,

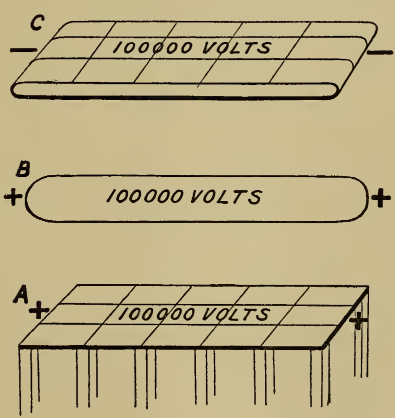
$$V = {}^2/_3\, \pi \rho a^2$$

$$\rho = 3V/2\, \pi a^2.$$

Suppose $V$ equals 38 volts or 0.127 electrostatic units *C. G. S.;* $a$ equals 50 cm. and $\rho = 2.4 \times 10^{-5}$, the electrostatic force at a distance $r$ being ${}^4/_3\, \pi \rho r = 10^{-4} r$.

Hence a small body electrified with a quantity of electricity equal to that possessed by a cubic centimetre of air and placed midway ($r = 25$) between the surface and centre of the inclosure experiences a force equal to $2.4 \times 10^{-9} \times 25$ or $6 \times 10^{-8}$, or approximately $6.10^{-5}$ grammes, which is 4.8 per cent. of the force of gravity on a cubic centimetre of air of density 1/800. "During a thunder storm," says Kelvin, "the electrification of air, or of air and the watery spherules constituting cloud, need not be enormously stronger than that found in our experiments." (In the experiments referred to below higher values were obtained.) "This we see by considering that if a uniformly electrified globe of a metre diameter produces a difference of potential of 38 volts between its surface and centre, a globe of a kilometre diameter, electrified to the same electric density, reckoned according to the total electricity in any small volume (electricity of air and of spherules of water if there are any in it), would produce a difference of potential of 38,000,000 volts between its surface and centre. In a thunder-storm, flashes of lightning show us differences of potentials of millions of volts, but not perhaps of many times 38,000,000 volts, between places in the atmosphere distant from one another by half a kilometre."

One may go farther and say that in this electrification of air may lie the possibility of principles valuable in aerial navigation, for as in the ordinary Thomson electrometer the aluminum needle between the quadrants moves always from the region of high (positive) to the region of low (negative) potential, so if the potentials are sufficiently high a charged body free to move in the air will move from the place of high to the place




of low potential. Thus in the accompanying diagram if $A$ represents a highly charged (and by this we mean voltages in the hundred thousands) insulated conductor, $B$ a mobile conductor charged equally high and same sign as $A$, then $C$ an oppositely charged mass, B will move from $A$ to $C$.

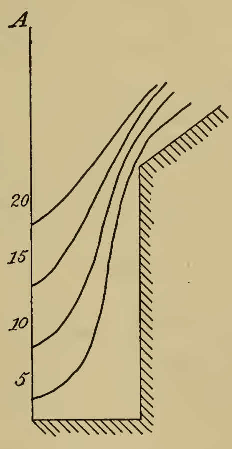
J. J. Thomson (see "Nature," July 26, 1894) holds that a molecule of gas cannot be electrified, but that the atoms may be. The question as it presents itself to his mind is, "Is the electricity in the charged gas carried by molecules or atoms?" "A square centimetre of surface immersed in air at standard temperature and pressure is struck by about $10^{15}$ molecules per second, yet such a surface will retain for hours without sensible loss a charge of electricity which, as we know from the electrolytic properties of liquids and gases, could be carried by a few thousand million of particles if these were to receive such a charge as the atoms of the air are able to carry."

We see, then, how much remains to be determined and how valuable in connection with the proposed electrometric survey the aero-physical laboratory would be.

Returning now to the results of Elster and Geitel, under their fourth deduction it is said that the morning maximum in the potential curve was not observed at a height of 10,168 feet. This, we think, is a most interesting result, and the result should be confirmed or disproved without delay. If need be, observations of the potential at great heights could be made by the aid of kites. With regard to the fifth result, the positive fall of potential within a cloud which gave but a small quantity of rain, we can only say that the whole subject of the relation of potential to rainfall calls for investigation. Much has been surmised and but little done. Our experimental evidence is scanty, being limited to a stray observation here and there. One interesting observation made on August 9, 1892, may be referred to. A kite connected by wire with a quadrant electrometer was raised and kept at some elevation above the summit of Blue hill, Massachusetts. At 7.40 p. m. a thunderstorm, which for some twenty minutes had been approaching from the west, was near enough to cause an incessant stream of sparks from the kite string. When the string was connected over a Mascart insulator to the electrometer—*i. e.*, the needle, one set of quadrants being charged highly positive and the other highly negative—a sizzling discharge occurred. Stinging shocks could be felt on touching the kite wire, and if a ground wire near by was held within a fraction of an inch a discharge of sparks ensued. Rain began about 8.10 p. m. and ended in a few minutes, the amount being about one-hundredth of an inch; lightning was frequent and vivid to the north and northeast, and, as we learned the next day, did much damage to barns in that locality. Although the electrical phenomena were to be seen thus plainly from ten to fifteen miles away, we were not able after the rain to obtain sparks from the kite wire. This seems therefore to confirm the Sonnblick observation.

With regard to Saint Elmo's fire, it is of interest to quote in conjunction with the Sonnblick experiments the Ben Nevis observations. Buchan states that from 1883 to 1888 fifteen cases of Saint Elmo's fire had been observed. All occurred during the night-time, indicating that there is no electrometer at the observatory and no means of determination other than visibility, from September to February. On one occasion it was heard during the daytime. All cases were noticed during the prevalence of well-marked lows, generally about six hours after the center had passed.

*Observations of the Potential.*—The first source of error in determining the true potential of a point in air is to be found in the bending of the equipotential lines by the walls of buildings, the sides of mountains, hills, etc. In a rectangular court fifteen metres wide, with walls twenty-five metres high and forty metres long, it was found by Exner; (see "Repertorium der Physik," xxii, heft 7) using a collector suspended by a silken cord and connected with a quadrant electrometer in such a way as to be readily moved up or down and from one side to another, that the value of the potential varied. The contour of the potential surfaces was approximately that shown in the accompanying diagram. With the collector two metres from the wall, at heights of 5, 10, 15, and 20




metres, the potentials were 2, 7, 17, and 48 volts respectively. With the collector in the centre of the court, at the same heights, the values of the potential were 5, 11, 32, and 68 volts. The determination is open to criticism, however, in this: that, the potential being at times exceedingly variable, no method in which but one collector is employed can give conclusive results. The experiment should be tried with two similar collectors. The experiments made in Washington a few years ago by the Signal Service (see Mendenhall, Memoirs of the National Academy) are therefore preferable, inasmuch as two electrometers calibrated to give like deflections for like voltages were employed. The collectors were frequently interchanged and other checks applied. The following mean values were obtained:

| Height. | Potential at beginning. | After five minutes. |
|---|---|---|
| 6.1 m. | 20 volts. | 30 volts. |
| 7.7 | 38 | 51 |
| 9.1 | 48 | .. |
| 12.0 | 60 | 72 |
| 16.8 | 121 | 141 |

Notice that a time element comes into the discussion, for it appears that the collector requires some little time to come to the potential of the air. Again, it appeared that by varying the rate of flow the values would be somewhat altered, and it would therefore be necessary in any extended survey to use not only similar instruments but similar times. Pellat (see "Comptes Rendus," March, 1885, p. 375) found while studying the means employed to get the potential of the air that with a flow of eight litres in twelve hours about six minutes were required for the electrometer to attain the proper value, while with a flow of twelve litres only five minutes were needed. Water-droppers are the collectors most generally used, but there are other forms, and in some ways preferable. The paper match (blotting paper soaked in nitrate of lead) is slower than the water-dropper and gives somewhat lower values.

Assuming that a proper collector can be designed and the error due to bending corrected, we have as the first problem the determination of the potential gradient at any height. Exner (see "Ursache und Gesetze der Atmos. Elec.") experimented with balloons carrying insulated water-droppers. Three sets of observations were made at 400, 550, and 660 metres, with the hope of getting an approximate value for 500 metres. A constant value of 193 volts was obtained, but the constancy is perhaps due to the fact that the balloon traversed the distance in a few minutes. From measurements made with small balloons he obtained for the potential in free air—

| Metres. | Volts. | Metres. | Volts. |
|---|---|---|---|
| 17 | 100 | 25 | 160 |
| 18 | 110 | 27 | 170 |
| 20 | 120-140 | 30 | 195–210 |
| 21 | 130 | 34 | 250 |
| 22 | 160 | 40 | 280 |
| 25 | 160 | | |

and from these $\frac{d^2v}{dn} = 6.8$ volts per metre.

These values were obtained, however, with a burning match-collector, and we propose to apply a correction to them for that reason. Sir William Thomson, in a paper read before the meeting of the British Association in 1889, gives observations made by McLean and Goto for that year, showing "that an enclosed mass of air is electrified negatively by the burning of a paraffin lamp, of coal gas, of sulphur, magnesium, and several other substances, while, on the other hand, the burning of charcoal electrified a room positively." In some experiments made by us in 1890 it was found that the flame in the dark room where the electrometer was installed electrified the air of the room and materially affected the readings. The electrification amounted to as much as 19 or 20 volts negative, while an average value for the air outside (the nozzle of the collector was about a metre from the wall and 12 metres from the ground) was 50 volts positive. Ventilating the room thoroughly, we found, caused a disappearance of this negative electrification. We would reduce the value 6.8 volts found by Exner to something like 34 volts, following Pellat's relative weights of 1, 5, and 10 for match, water, and flame.

Another set of observations made upon an exposed mountain side gave Exner the following values:

| Metres. | Volts. | Metres. | Volts. |
|---|---|---|---|
| 3 | 110 | 18 | 520-550 |
| 5 | 140–150 | 19 | 550 |
| 6 | 210 | 20 | 660 |
| 7 | 230–250 | 25 | 820 |
| 12 | 280–405 | 30 | 970 |
| 14 | 480 | | |

which would make the linear potential gradient of much higher value. Valuable observations were made by the United States Signal Service under the supervision of Dr. Mendenhall. A résumé of the observations can be found in Third Memoir, vol. v, National Academy of Sciences. The influence of varying temperature and humidity were in part eliminated by a long series of observations. The instruments used were modified Mascart electrometers and large similar water-droppers. The methods and adjunct apparatus were alike at all stations.

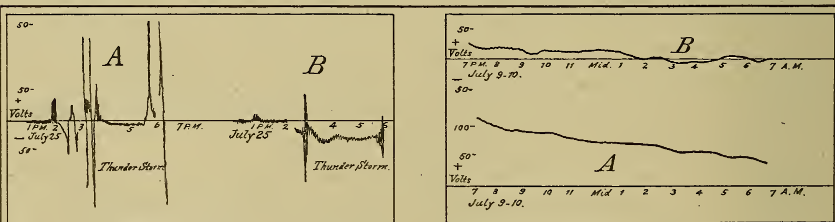
For the particular question which we are discussing—the potential gradient—we are obliged to refer to a table not found in the published report, although it was one of the most important. This table gives the most extensive and comparable values yet obtained for determining the potential gradient in the lower layers of the air. The values are somewhat smaller than might be anticipated, but this may be explained by the proximity of buildings.

| Date. | Number of observations. | Mean value of potential. | | Difference for 138 metres. |
|---|---|---|---|---|
| | | High. | Low. | |
| June 26 | 399 | 289 | 134 | 155 |
| July 17 | 60 | 1,129 | 93 | 1,036 |
| July 20 | 107 | 389 | 70 | 319 |
| Sept. 21 | 40 | 212 | 107 | 105 |
| Oct. 4 | 94 | 586 | 192 | 394 |
| Oct. 5 | 82 | 300 | 108 | 192 |
| Oct. 7 | 97 | 435 | 112 | 323 |
| Oct. 14 | 87 | 140 | 24 (*a*) | 116 (*a*) |
| Nov. 1 | 4 (*b*) | 1,137 | 265 | 872 |
| Nov. 3 | 98 | 943 | 248 | 695 |
| Nov. 12 | 15 | —849 (*c*) | —254 (*c*) | —604 (*c*) |
| Nov. 12 | 65 | 458 | 36 | 422 |
| Dec. 15 | 13 | 487 | 4 (*d*) | 483 (*d*) |
| Jan. 29 | 26 | 413 | 141 | 272 |
| Feb. 9 | 54 | 1,825 | 89 | 1,736 |

(*a*) Denotes values at lower station below zero.
(*b*) Observations not simultaneous; differing few minutes.
(*c*) During rain; negative values at both stations.

We have, therefore, a mean value for the potential of the air, at an elevation of 500 feet, of 637 volts. If we omit negative values and consider only positive we obtain 543 volts, or, roughly, 4 volts per metre elevation. We have no right, however, to omit the negative values, and the true value for free air would be doubtless higher than the figure here given. For the lower station we find the mean value of the potential to be about one-fifth of that at the upper, while the elevation is about one-eleventh.

*Thunder-storms.*—As might be anticipated, there are some remarkable variations in the potential during thunder-storms. We are able to record the time of lightning by well-marked variation in the potential. The accompanying diagrams show the potential variations during a thunder-

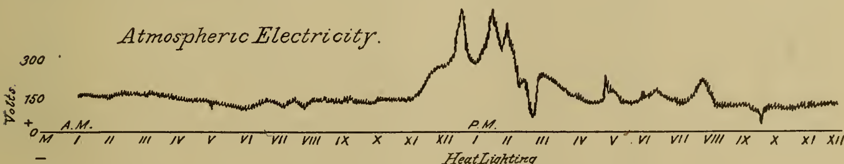



*Electrical Potential of the Air Photographically registered at two Stations.*
*A.- 194 m. above Sea-level and B - 74 m. above Sea-level.*

storm at both an upper and a lower station. For purposes of comparison, some characteristic fair-weather curves are given. Thunder-storms cannot be studied to the best advantage until the electrometer comes into general use. Disruptive discharges occur when the stress in the atmosphere between the cloud and ground exceeds a certain value, determined, of course, by conditions of pressure, humidity, and dustiness. As the heavily charged cloud approaches the locality where the electrometer is placed, the needle indicates a steadily increasing strain. When this tension exceeds the dielectric strength of the air the lightning occurs. The dielectric strength of the air, according to Sir William Thomson. under ordinary conditions of temperature and pressure, is about 9,600 grains weight per square foot, or about 1.37 pounds. This is equivalent to 656 dynes per square centimetre. The pull, then, which the air ordinarily can withstand is not over .67 of a gramme per square centimetre.

In the daytime many flashes of lightning may pass unnoticed, and even in the night-time some may be unobserved; but, aside from these, there exists a myriad of minor discharges which are all unknown to the eye. Hence the electrometer method, which enables us to take cognizance of minor discharges, constitutes a decided advance. Another way of accomplishing the same end would be the employment of properly tuned Hertzian resonators. It is *quite possible to time lightning flashes without seeing them*, and this we accomplished a few years ago in the tower of the Smithsonian Institution. An observer, with watch in hand, was asked to time all flashes which he saw. Meanwhile, in a darkened room, we studied the movements of the needle. The times of lightning were found to correspond with certain disturbances in the potential. The agreement is very close, except that there will always be found to be more disturbances than recorded flashes, indicating, perhaps, that there are discharges which the eye does not see.

Thunder-storms are not the only atmospheric disturbance in which the electrification of the air varies in a noteworthy manner. We have found most remarkable perturbations of the potential occurring during snowstorms. We give the following record at great length because we think it is the most accurate record as yet available. It shows that *a snowstorm is closely akin to a thunder-storm.*




We have, too, the potential variations during heat lightning, and still more, the relations to auroral displays, all awaiting systematic investigation. Is it too much to say that in no other way can research be so profitably pursued as in connection with the electrification of the air?

*Potential Fluctuations During Snowstorm, March 5 and 6, 1890.*

| Time. | Potential in volts. | | Time. | Potential in volts. | |
|---|---|---|---|---|---|
| | Positive. | Negative. | | Positive. | Negative. |
| 5:30 p. m | 70 | | 10:35 a. m | | 60 |
| 40 | 70 | | 36 | | 65 |
| 6:00 | 70 | | 37 | | 250 |
| 05 | 45 | | 38 | | 85 |
| 10 | 37 | | 39 | | 157 |
| 9:00 a. m | | 25 | 40 | | 157 |
| 30 | | 312 | 50 | | 275 |
| 40 | | 250 | 51 | | 200 |
| 42 | 75 | | 52 | | 300 |
| 43 | | 125 | 53 | | 150 |
| 44 | | 250 | 54 | 75 | |
| 45 | | 125 | 55 | 110 | |
| 47 | 200 | | 56 | 250 | |
| 48 | 150 | | 57 | 500 | |
| 49 | 250 | | 57:30 | | |
| 50 | 100 | | 45 | | 50 |
| 51 | 250 | | 58 | 7 | |
| 52 | 275 | | 59 | 500 | |
| 53 | 325 | | 11:00 a. m | 250 | |
| 54 | 350 | | 01 | 162 | |
| 55 | 212–275 | | 02 | 182 | |
| 57 | 250 | | 03 | 10 | |
| 58 | 150 | | 04 | 75 | |
| 59 | 275 | | 05 | Over 575 off | scale and |
| 10:00 a. m | 200 | | | continued | so until— |
| 01 | 225 | | 10 | 100 | |
| 02 | 275 | | 10:15 | 115 | |
| 03 | 312 | | 11 | | Off scale neg. |
| 04 | 287 | | 20 | | Off scale neg. |
| 05 | 200 | | 21 | | 300 |
| 06 | 250 | | 22 | | 450 |
| 07 | 210 | | 23 | | 475 |
| 08 | 162 | | 24 | | 275 |
| 09 | 170 | | 25 | | 275 |
| 10 | 100 | | 26 | | |
| 13:30 | 25 | | to | | Off scale neg. |
| 14 | 105 | | 33 | | |
| 16:30 | 300 | | 34 | | 225 |
| 17 | 187–250 | | 35 | | 150 |
| 18 | 45 | | 36 | 200 | |
| 18:15 | | 75 | 37 | 175 | |
| 19 | | 8 | 38 | | 75 |
| 19:30 | 188 | | 39 | | 15 |
| 20 | 125 | | 40 | | 65 |
| 21 | 115 | | 41 | | 56 |
| 22:30 | 50 | | 42 | | 60 |
| 23 | 90 | | 43 | | 80 |
| 24 | 95 | | 44 | | 65 |
| 25 | 50 | | 45 | | 80 |
| 26 | 50 | | 50 | | 190 |
| 27 | | | 12:05 a. m | | 137 |
| 27:30 | 160 | | 15 | | 170 |
| 28 | 175 | | 25 | | 207 |
| 29 | | 250 | 30 | | 185 |
| 30 | | 100 | 45 | | 237 |
| 31 | | 80 | 55 | | 195 |
| 31:30 | 20 | | 2:30 p. m | 140 | |
| 32 | | 20 | 35 | 175 | |
| 33 | 100 | | 40 | 157 | |
| 34 | 150 | | | | |

We have referred above to the possibility of studying electrical discharges in the atmosphere from an entirely new standpoint. The method would consist in the use of a resonator or resonators, with proper vibration periods, capable of responding to the ether oscillations. The rapidity of vibration in any electrical system being directly proportional to the linear dimensions, we may assume for a flash of lightning one thousand meters long the existence of vibrations at a rate of, say, three hundred thousand per second.

Dr. Lodge (see "Phil. Mag.," August, 1888), has worked out at some length the values for an ordinary flash of lightning.

Now $V$, the velocity of propagation, is equal to $\frac{1}{(\sqrt{\mu K})}$ and the wave-length $\lambda = VT = 2\pi\sqrt{\frac{L}{\mu} \cdot \frac{S}{K}}$ where $\frac{L}{\mu}$ is the electromagnetic measure of induction and $\frac{S}{K}$ is the electrostatic measure of capacity.

$$\lambda = \frac{2\pi V}{p} = 2\pi\sqrt{\frac{LS}{\mu K}}. \qquad p = \frac{1}{\sqrt{LS}}.$$

We may expect the longest sparks when the periods of the cloud-earth system and the proposed resonator are the same. The length of each conductor, then, should be half a wave-length or some multiple of half a wave-length.

Such resonators may occur naturally, and perhaps herein is an explanation of sympathetic distant flashes which are sometimes seen, the second flash being the response of a natural resonator.

## Conclusion.

An aero-physical laboratory would afford opportunity for important research and investigation. A most promising field, we have attempted to show, lies in the increase of knowledge of conditions controlling the weather. We urge investigations in all lines bearing upon forecasting or foretelling weather. As examples of proper and profitable lines of study in this direction, let us mention: v. Helmholtz on "Studies of viscosity effects in the general circulation of the atmosphere;" "Studies of the mutual influence of whirls." Practical application of knowledge of this character being the great desideratum of modern meteorology. For example, Helmholtz gives as a practical deduction in one of his papers the statement that extremely violent winds are prevented in the general circulation by whirl action—*i. e.*, by the mixing which a whirl with its relatively large surface can accomplish. Again, his study of wave-action at the common boundary of two fluids or of a fluid and a gas has a practical application in the measurement of air billows. We may some day correlate the wave frequency and character with the force and direction of the wind. Oberbeck's papers on the "Motions of the atmosphere," Hertz's "Graphic method of showing the adiabatic changes in moist air," and v. Bezold's "Thermodynamics of the atmosphere" are all excellent illustrations of valuable research work along the lines we advocate. The two last named are of particular value to the forecaster, and v. Bezold's work gives an insight into the physical processes brought into action as a given mixture of air and vapor passes through various levels and environments. He treats of just such conditions as the forecaster is likely to meet. We want to be able to forecast with certainty the formation and dissolution of fog and cloud, and we must therefore know the air mixture, the quantity of heat, the cycles of cooling by contact and radiation, and the adiabatic expansions and compressions for various levels. When such data are accessible, the forecasting of weather will move from its present resting place of empiricism. We have further tried to point out the value of determinations of the total moisture in any given stratum of atmosphere. Although the problem is far from being an easy one and far more involved than appears at first glance, we believe that it is within our power from systematic study of the absorption lines due to water vapor to ascertain the vapor distribution. The infra-red portion of the spectrum, being rich in these lines, should be explored with this end in view.

In another direction, that of atmospheric electricity, we urge experimentation, for we believe that therein may lie possibilities of great extension of our knowledge of atmospheric phenomena. We know almost nothing of the electrification of the atmosphere; how the air acquires its charge we do not know, and of the distribution of the potential and the significance of its variations we have only fragmentary and scant knowledge. In 1752 an experiment, simple enough in its details, demonstrated the nature of the lightning flash. In 1895 the aurora, the origin of the electricity of thunder-clouds, and similar questions are as the nature of the lightning was one hundred and forty-three years ago. In what direction have we a more promising field for the increase and diffusion of "knowledge of the nature and properties of atmospheric air in connection with the welfare of man?"