THE FREE IONS IN THE ATMOSPHERE OF THE TROPICS.

By J. R. Wright and O. F. Smith.

A STUDY of atmospheric electricity involves, among its several phases, the determination of the number of free ions per unit volume in the earth's atmosphere together with the variation of this number due to altitude, location, and meteorological conditions.

The first attempt to measure the ionization of the free atmosphere was made by Elster and Geitel[1] while investigating the causes of the discharge of electrified bodies surrounded by air in closed vessels. They found that when a piece of wire gauze, connected to an electroscope, was exposed to the open air both positive and negative electricity was discharged at a much more rapid rate than when placed in a closed vessel, also that the rate of discharge of positive and negative was generally different. The rate of discharge was taken as a measure of the ionization, but, since by this method they had no means of determining the volume of the air tested, quantitative measurements were impossible and only comparative values were obtained.

A short time later an instrument was devised by Ebert[2] which made the determination of the number of positive or negative ions present per cubic centimeter in the atmosphere comparatively easy. With this apparatus determinations have been made at various points on the earths' surface by different observers, and although the individual results vary greatly the general conclusions that have been drawn are fairly uniform.

During the past two years we have been investigating atmospheric-electric phenomena at Manila and vicinity and as a part of that work have made a large number of determinations of the free ions present. These observations were taken by an improved form of Ebert's apparatus made by Gunther and Tegetmeyer of Braunschweig, Germany. It has a vertical rather than a horizontal collecting cylinder, and a Wulf[3] electrometer in the place of the Elster and Geitel electroscope. The theory of the instrument is well known, but a brief discussion seems of value here for the sake of completeness. A certain volume of air,

[1] Phys. Zeit. (1900), 2, 116; (1901), 2, 560.
[2] Phys. Zeit. (1901), 2, 662.
[2] Phys. Zeit. (1909), 10, 152.

measured by an air meter, is drawn between concentric cylinders by means of an air turbine which is operated by clock work. The inner cylinder, which is carefully insulated, is charged to a known potential and connected directly to the quartz fibers in the Wulf electrometer. The voltage discharge is therefore easily measured. Knowing the capacity of the instrument, the number of ions per cubic centimeter is given by the equation $N = CE/eV$, where N represents the number of ions per cubic centimeter, V the volume of air drawn through, C the capacity of the instrument, E the fall in potential (corrected for the natural leak), and e the ionic charge.

The capacity of our apparatus was 16.25 electrostatic units, the free area between the concentric cylinders being 6.87 square centimeters, and the inner rod 40 centimeters long. Since the rate of flow of air was on the average 1.25 liters per second, the time required for an ion to pass through the instrument was approximately 0.22 second. The range of voltage used was from 175 to 165, thus all ions having a mobility greater than 0.033 centimeter per second per volt centimeter were caught by the apparatus.

Through the work of Langevin,[1] Mache and von Schweidler,[2] Pollock,[3] and others, the atmospheric ions have been classified according to their mobilities into the three following types:

Type of Ions.	Mean Value of Their Mobility.
Small	1.02 to 1.8
Intermediate	0.1 to 0.006
Large	0.0003 to 0.0008

It is evident, therefore, that under the conditions of the experiment, the instrument should record all the small ions and a portion of the intermediate ions. However, since we were always careful to charge as nearly as possible to the same potential, the proportion of intermediate ions caught ought to be nearly constant.

The limited time at our disposal for the present work, and the large number of factors that may influence the ionization of the atmosphere, made an exhaustive study impossible. Consequently, the work was confined to the following points:

1. The effect on the ionization of the character of the light in which the determinations are made.
2. The determination of the number of positive and negative ions per cubic centimeter in the atmosphere and the variation of this number with altitude, location, and relative humidity.
3. The ratio of the positive to the negative ions.

[1] Comptes Rendus (1905), 140, 232.

[2] Phys. Zeit. (1905), 6, 71.

[3] Science (June, 1909).

The Effect on the Ionization of the Character of the Light in which the Determinations are Made.

The effect of tropical sunlight on the atmosphere is an unsettled question and has been the subject of several articles appearing in the Philippine Journal of Science. In an article by R. F. Bacon[1] two conclusions are drawn, neither of which seems to be substantiated by the data quoted. The author first states that tropical sunlight ionizes the air, and concludes that the ionization of the atmosphere in the tropics is greater than in temperate or colder regions. To support these claims, observations were taken on the rate of discharge of an electroscope when air was drawn through it at a known rate, first in the dark, then in the diffuse light of the laboratory, and finally in the bright sunlight.

The results recorded are very consistent and show a mean rate of discharge of 6.5 volts per hour for darkness, 15.6 volts for diffuse light, and 35.7 volts for sunlight. However, these results can scarcely be taken as a measure of the ionization produced by the tropical sun, and it is impossible to explain just why such consistent data were obtained, since no diagram or description of the apparatus is given. It was also impossible to learn whether the observations in the darkness or the diffuse light were made on the confined air of the laboratory or otherwise.

We have also been unable to decide how Bacon arrived at the conclusion that the ionization is greater in the tropics than in temperate regions. His results are expressed in volts per hour, no attempt being made to reduce the readings to ions per cubic centimeter. Moreover, since the electrical capacity of his testing apparatus is not given, sufficient data is not at hand to permit the reader to make the necessary calculations. A mere statement of the leak per hour expressed in volts, is certainly insufficient to permit a comparison with readings taken with different instruments and under different conditions.

From the nature of the experiments it seems that what was really attempted was to measure the effect on the ionization of the character of the light in which the determinations were made. The author himself seems to be in some doubt for he says:

"However, I incline to the view that the ionization observed may not be a direct effect of the tropical sunlight on the air, but may be a secondary phenomenon connected with the large amount of moisture in the air of tropical islands and with the luxuriant vegetation of this region."

This view seems to carry with it the idea that the ionization would be the same, both on the outside and inside of a building, unless the air in the latter case was stagnant or contaminated with some ionizing agent.

[1] Phil. Jour. Science, Sec. A (1910), 5, 267.

Further on in discussing the work of Elster and Geitel,[1] the author states in substance:

"It is a curious coincidence, if nothing more, that days when the sky is about half overcast are days . . . when the activity of the sun is greatest . . . on the ionization of the air." This statement seems entirely contrary to the conclusion drawn directly from his data.

In view of this article it was deemed advisable to make some determinations to ascertain whether or not the ionization readings are a function of the character of the light in which the apparatus is placed. Consequently observations were made with the Ebert's ion-counter, in the dark, in the diffuse light of the laboratory, and in the bright sunlight.

For the inside readings at Manila, the instrument was always placed by an open window, and a good circulation of air maintained by means of an electric fan. Readings were never taken until the room had been open to the outside for some time. For the outside readings the apparatus was placed on a stand in the open just outside the physics building. The results are given in Table I. A few observations taken on Mount Pauai, Luzon, Philippine Islands, are also included in the table.

The mean values for Manila show no appreciable difference for the different kinds of light. At Mount Pauai the mean value for darkness is much greater than for sunlight, but no importance is attached to this fact, since the high value at Pauai is probably due to the relative humidity, a point which will be discussed later. Furthermore, the observations in the sunlight at Mount Pauai were taken at a time when the ionization was very low, as shown by the reading in the diffuse light taken immediately following those in the sunlight, which gave a value of 432 ions per cubic centimeter.

Our results are in good agreement with those of Schuster,[2] who obtained the same ionic density both in the open air and inside the physical laboratory. McClellan and Kennedy[3] also found no apparent difference between night and day readings.

The Determination of the Number of Positive and Negative Ions per Cubic Centimeter in the Atmosphere and the Variation of this Number with Altitude, Location, and Relative Humidity.

The mean values obtained for the specific numbers of both positive and negative ions at Manila, on Mount Pauai, and at Baguio, are given in Tables II., III., and IV., respectively. The determinations were taken

[1] Ann. der Phys. (1900), 2, 425.

[2] Proc. Man. Phil. Soc. (1903–4), 48, No. 12, 1.

[3] Proc. Roy. Irish Acad., Sec. A, 30, No. 5, 72.

TABLE I.

Effect of Light on the Ionization of the Atmosphere.

Place.	Date.	Time.	Ions per c.c.	Character of Light.	Remarks.
	1914	a.m. p.m.			
Manila........	March 30	7.15	346	Darkness	All readings are on the positive ions.
Do.	Do.	8.15	562	Do.	
Do.	Do.	9.15	383	Do.	
Do.	Do.	10.15	390	Do.	
Do.	March 31	12.24	591	Do.	
Do.	Do.	1.30	405	Do.	
Do.	Do.	2.30	1,360	Do.	
Do.	Do.	3.30	1,154	Do.	
Do.	Do.	4.00	888	Do.	
Do.	Do.	5.15	324	Do.	
		Mean.	640		
Manila........	June 10	9.15	655	Diffuse	
Do.	Do.	9.45	971	Do.	
Do.	Do.	10.45	1,302	Do.	
Do.	(*a*)	....	597	Do.	Mean of 91 observations.
		Mean.	609		
Manila........	June 10	11.00	471	Bright sun	
Do.	Do.	11.30	719	Do.	
Do.	Do.	12.00 noon	532	Do.	
Do.	June 11	9.30	791	Do.	
Do.	Do.	10.00	590	Do.	
Do.	Do.	11.00	554	Do.	
Do.	Do.	11.30	640	Do.	
Do.	Do.	12.00 noon	504	Do.	
		Mean.	596		
Mount Pauai..	(*b*)	....	2,634	Darkness	Mean of 17 observations.
Do.	(*c*)	....	1,254	Diffuse	Mean of 50 observations.
Do.	April 30	(*d*)	468	Bright sun	Mean of 3 observations.
Do.	Do.	12.00 noon	432	Diffuse	Mean of 2 observations.

(*a*) From December, 1913, to March, 1914.
(*b*) From April 23, to 29, 1914.
(*c*) From April 20 to 30, 1914.
(*d*) From 9.00 a.m. to 10.00 a.m.

in every case at a place which was comparatively far from any source of dust or smoke, so that the air tested was of a high degree of physical purity. This was especially true for Mount Pauai and it is an extremely important factor in a comparative study of our results, since Eve[1] has shown that the presence of dust, smoke, or other nuclei may cause a variation of more than 50 per cent. in the ionization as recorded by

[1] Phil. Mag. (1913), 19, 657.

Ebert's instrument. The natural leak was always determined just before and immediately after a reading and the observations corrected accordingly.

TABLE II.

Mean Values of Ionic Density at Manila; Elevation 3 Meters.

Date.	Positive.			Negative.		
	Mean.	Maxi-mum.	Mini-mum.	Mean.	Maxi-mum.	Mini-mum.
1913						
December 8	579	1,110	253	1,152	1,621	402
9	487	519	446	677	777	576
15	504	569	382	557	843	369
23	2,782	3,047	2,516	23,327	45,860	1,815
24	1,116	2,555	324	446	447	445
29	561	656	489	564	708	447
1914						
January 1	400	565	202	408	565	291
5	351	454	232	353	526	258
6	487	512	461	473	663	282
12	609	664	582	497	548	418
13	420	512	324	317	338	296
14	400	433	366	267	267	267
19	363	512	274	378	483	288
20	346	353	339	275	275	275
26	322	360	260	332	353	311
27	156	195	116	311	311	311
28	412	412	412	.....	.....	.....
29	402	462	296	325	412	275
February 2	982	2,080	383	997	1,560	434
3	613	731	383	673	710	636
9	713	900	390	436	436	436
10	601	841	282	695	993	397
16	418	569	274	432	576	295
17	418	598	295	423	562	188
24	324	324	324	.....	.....	.....
March 30	627	2,101	324	.....	.....	.....
Mean value of the positive ions for 91 observations = 597.				Mean value of the negative ions for 50 observations = 523.		

From the tables it is seen that the values for Manila are consistently lower than those for the higher altitudes, and in fact somewhat lower than the average values obtained by most observers in other parts of the world. The number of each kind, as usually given, being between 1,000 and 2,000 per cubic centimeter. Apparently, the high values for high elevations are not due to altitude alone for the values obtained at Baguio, elevation about 1,500 meters, are uniformly higher than those on Mount Pauai, elevation 2,460 meters.

TABLE III.

Mean Values of Ionic Density at Mount Pauai; Elevation 2,460 Meters.

Date.	Positive.			Negative.		
	Mean.	Maximum.	Minimum.	Mean.	Maximum.	Minimum.
1914						
April 20	724	929	476	....	....	....
21	1,548	2,980	489	....	....	....
22	914	1,679	482	1,239	1,740	737
23	2,142	5,086	849	....	....	....
24	2,712	4,225	1,109	....	....	....
25	843	1,242	649	989	1,387	598
28	2,102	4,521	303	....	....	....
29	2,083	3,079	1,118	....	....	....
30	663	1,478	234	....	....	....
Mean value of the positive ions for 66 observations = 1,694.				Mean value of the negative ions for 5 observations = 1,089.		

TABLE IV.

Mean Values of Ionic Density at Baguio; Elevation 1,500 Meters.

Date.	Positive.			Negative.		
	Mean.	Maximum.	Minimum.	Mean.	Maximum.	Minimum.
1914						
May 7	4,389	7,295	2,648	....	....	....
8	3,427	7,998	942	....	....	....
9	7,265	13,560	1,342	6,283	12,620	1,110
11	3,524	9,508	1,108	4,975	9,180	1,442
12	2,396	4,480	1,136	....	....	....
Mean value of the positive ions for 30 observations = 3,845.				Mean value of the negative ions for 7 observations = 5,526.		

To explain the higher values for the ionization at high altitudes, there are several factors that must be considered. Among these are; the increased ionizing effect of the ultra-violet rays of the sun, the accumulation of ions due to the concentration of the earth's electrical charge at points, and the variations in the relative humidity. The only factor that we were able to investigate in the present work was the relative humidity.

In Table V. is given a summary of the mean values of the relative humidity and the ionization at different altitudes, together with the mean of the daily means. It is interesting to note here that although the relative humidity is higher at the higher altitudes, the absolute humidity is almost invariably lower.

TABLE V.

Mean Values of Relative Humidity and Ionic Density.

Place.	Elevation, Meters.	Relative Humidity.		Ionic Density.	
		Mean, Per Cent.	Mean of Daily Means, Per Cent.	Mean.	Mean of Daily Means.
Manila...........	3	66.0	65.6	597	591
Baguio...........	1,500	78.9	79.1	3,845	4,200
Mount Pauai.....	2,460	81.1	77.4	1,694	1,525

The mean of the daily means gives the most reliable data, as the average of all observations would be materially influenced by grouping the determinations during a period of either high or low relative humidity. Throughout our observations a condition of fog, mist, or rain, invariably gave a high value for the ionization. This is well demonstrated in Table II. by the observations of December 23 when the negative ions increased from 1,815 to 45,860 in a period of about two hours, the weather changing from partly cloudy to a heavy shower.

The effect of the humidity on the ionization is also well shown by Figs. 1 and 2 in which the relative humidity and the ionization for 24-hour

Fig. 1.

Ionization and relative humidity curves for April 23 and 24, 1914, at Mount Pauai.

periods at Manila and on Mount Pauai are plotted against the time of day.

The ionization curve lags slightly behind the humidity curve as might be expected, but on the whole the two curves show too great a uniformity to be purely accidental. In all our observations there was no apparent

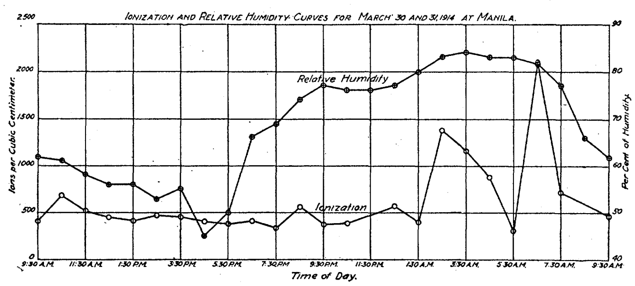

Fig. 2.

Ionization and relative humidity for March 30 and 31, 1914, at Manila.

relation between the maximum and minimum values and the time of day, except in so far as the time of day influenced the value of the relative humidity. This probably accounts for the high values obtained for darkness at Mount Pauai, as shown in Table I., since the relative humidity was nearly always greater at night.

No attempt has been made to measure the large ions in the atmosphere, the number of which, as shown by the work of Langevin,[1] Pollock,[2] McClelland and Kennedy,[3] and others is much larger than that of the small ions. The mean values given in Table VI. are for the ionization as recorded by Ebert's apparatus.

For the sake of comparison a brief summary of the results of some other observers is given in Table VII.

TABLE VI.

Mean Values of Small Ions Recorded by Ebert's Apparatus.

Place.	Elevation, Meters.	n_+	n_-
Manila	3.0	587	523
Mount Pauai	2,460.0	1,694	1,089
Baguio	1,500.0	3,845	5,536

From a general survey of the literature on the subject of atmospheric ionization and the published results of investigations, it is evident that

[1] Loc. cit.
[2] Loc. cit.
[3] Loc. cit.

a large amount of experimental evidence must yet be obtained before any definite conclusions may be drawn. The work thus far shows that the ionization varies between wide limits, not only from day to day but from hour to hour. The limits of this variation, also, seem to be

TABLE VII.

Mean Values of Small Ions as Recorded by Other Observers.

Observer.	Place.	n_+	n_-	Reference.
Boltzmann	Over Ocean	1,150	800	Phys. Zeit., 1904.
Simpson	Lapland	1,120	972	Phil. Trans., 1905.
Eve	Over Ocean	975	783	Phil. Mag., 1907.
Eve	Montreal and Quebec	323	372	Do.
Eve	Gulf of St. Lawrence	761	743	Do.
Schuster	Manchester	3,000		Proc. Man. Phil. Soc., 1904.

independent of the location in which the observations are made. Even the determinations taken over the ocean do not vary greatly from those over the land.

From our results it seems quite evident that the number of small ions in the atmosphere of the tropics is of the same order of magnitude as the number observed in other parts of the world, also that the number of ions per cubic centimeter increases with altitude and with relative humidity. The increase in ionization with altitude is contrary to the radio-active theory of atmospheric ionization, which as pointed out by Eve,[1] should decrease rapidly as we ascend from the surface of the earth. It is true that observations on a mountain peak do not give a true altitude effect, and yet some evidence of a decrease ought to be manifest, since the authors[2] in previous work found that the radium emanation content of the air at high altitudes is much lower than at sea level. It seems therefore, that there must be some other causes influencing the ionization which are as yet not completely determined.

THE RATIO OF THE POSITIVE TO THE NEGATIVE IONS.

The fact that the higher atmosphere carries a positive charge would necessitate that the positive exceed the negative ions in number. The mean value obtained for the ratio of positive to negative ions (1.17) however, is much larger than is necessary to explain the positive charge of the atmosphere. Eve[3] has pointed out that this apparent excess, as

[1] Phil. Mag. (1911), 21, 26.
[2] Phys. Zeit. (1914), 15, 31.
[3] Phil. Mag. (1910), 19, 657.

Table VIII.

Ratio of Positive to Negative Ions at Manila.

Date.	Interval. From —.		Interval. To —.		n_+	n_-	$\frac{n_+}{n_-}$	Weather Remarks.
1913	a.m.	p.m.	a.m.	p.m.				
Dec. 8	11.33			12.41	314	402	0.782	Following light shower.
8		2.36		3.46	1,110	1,527	0.727	
9	10.16		10.59		446	576	0.773	Variable, threatening.
9		2.32		3.42	508	777	0.654	Do.
15	11.06			12.24	475	461	1.032	Fair.
15		2.12		3.30	562	606	0.926	Do.
23	10.31		11.46		2,781	1,815	1.535	Variable.
24	10.44		11.56		568	447	1.046	Fair.
29	10.48		11.57		572	537	1.065	Do.
29		2.40		3.50	537	577	0.931	Do.
1914								
Jan. 2	11.07			12.14	498	565	0.883	Fair.
2		2.46		3.47	202	334	0.605	Do.
5	10.53		11.57		300	258	1.162	Do.
5		2.32		3.11	454	526	0.733	Partly Cloudy.
6		1.29		2.31	487	663	1.186	Fair.
12	10.45		11.52		663	526	1.206	Do.
12		1.56		3.05	582	483	1.206	Do.
13	10.10		10.59		375	338	1.110	Do.
13		3.08		3.49	512	296	1.730	Do.
14	11.20			12.02	366	267	1.371	Do.
19	10.44		11.46		289	362	0.799	Do.
19		3.28		4.31	512	386	1.329	Do.
20	9.12		10.19		346	275	1.258	Do.
26	11.30			12.08	346	353	0.981	Do.
26		3.00		4.06	310	310	1.000	Do.
27	9.00		10.07		156	311	0.500	Do.
29	9.06		10.17		373	289	1.290	Do.
29		1.43		2.48	462	344	1.345	Do.
Feb. 2	10.41		11.45		434	434	1.000	Do.
2		2.42		3.26	2,080	1,560	1.332	Cloudy with mist.
3	10.06		11.31		513	636	0.860	Do.
3		2.26		3.32	713	710	1.003	Do.
9		2.07		3.09	645	436	1.481	Fair.
10	10.09		11.10		667	993	0.673	Do.
10		1.54		3.00	536	397	1.351	Partly cloudy.
16	10.33		11.37		490	576	0.850	Fair.
16		3.11		4.15	274	360	0.760	Do.
17	10.00		11.02		328	188	1.748	Do.
17		2.29		3.33	598	540	1.110	Partly cloudy.

Mean value of ratio $\frac{n_+}{n_-} = 1.051$

measured by the Ebert's instrument, may be explained as due to the following causes:

1. A real excess.
2. More rapid diffusion of the negative ions to parts of the instrument, due to their greater mobility.
3. More rapid diffusion to centers; dust, smoke, mist, etc.
4. Apparent loading due to water vapor.

Consequently, the ratio as given by Ebert's ion-counter is probably in excess of the true value; furthermore, it is to be remembered that this instrument detects only the small and a portion of the intermediate ions.

In our determinations of this ratio three readings were taken in every case, so that any sudden change in the number of positive or negative ions would be detected. The results are given in Tables VIII. and IX.

TABLE IX.

Ratio of Positive and Negative Ions at Baguio and Mount Pauai.

Date.	Interval. From		Interval. To		n_+	n_-	$\frac{n_+}{n_-}$	Weather Remarks.
1914	1.m.	p.m.	a.m.	p.m.				
May 9....	11.40			12.47	4,117	5,120	0.804	Cloudy.
9....		2.05		2.38	13,560	12,620	1.074	Rain.
11....	8.35		9.08		2,201	1,442	1.540	Cloudy.
11....	11.05		11.43		2,604	4,638	0.567	Do.
11....		3.35		4.13	9,508	9,180	1.037	Do.
	Mean value of ratio $\frac{n_+}{n_-}$ for Baguio =						1.004	
April 22....	8.56		9.54		685	737	0.930	Slightly hazy.
22....		2.44		4.48	1,142	1,740	0.656	Cloudy.
25....	8.48		9.49		649	598	1.086	Fair.
25....		2.48		3.48	1,242	1,184	1.050	Cloudy.
30....	9.02		10.12		585	234	2,500	Bright.
	Mean value of ratio $\frac{n_+}{n_-}$ for Mount Pauai =						1.244	

Our mean value for Manila is 1.051; for Baguio, 1.004. These are both lower than the average given above, but our mean for Mount Pauai, 1.244, is decidedly higher. It is interesting to note that many of our observations give a value less than unity for this ratio. This means that the gradient of the electric intensity becomes negative. It is to be regretted that we were unable to take any observations on the potential gradient, for simultaneous readings on these two factors would be of interest.

Summary.

1. The number of positive and negative ions per cubic centimeter in the earth's atmosphere has been determined at Manila, Baguio, and on Mount Pauai. The ratio of the positive to the negative ions for the above mentioned places has also been investigated. These determinations were made with an Ebert's ion-counter.

2. The mean value obtained for the ionic density does not vary greatly from the value obtained by observers in other regions. The number increased with altitude and showed a fairly uniform tendency to follow the variations in relative humidity.

3. The ratio of the positive to the negative ions at Manila, and at Baguio, is less than the mean of earlier observers, while the value at Mount Pauai is greater. Many of the observations gave values less than unity, which shows that at times the gradient of the electric intensity has a negative sign.

Department of Physics,
University of the Philippines,
Manila, P. I.