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Air Ion Densities in a Smoke-Filled Room

PHILIP J. LORENZ[1]

Abstract. This study was concerned with the differentiation and measurement of small, intermediate, and large ion densities in a sealed room. It was found that the background density of large negative ions exceeded that of any other class. Under conditions of tobacco smoke pollution, large ions of both positive and negative charge were the major components of the air ion population. This was accompanied by a persistent attrition of high mobility ions both during and after smoking.

The study of air ions and their effects upon biological organisms has become an established area of biophyiscal investigation. There is a growing acceptance of air ionization as a factor affecting health and comfort. (Air ionizers for home use have been commercially available for several years.) Because many air pollutant particles are electrically charged, atmospheric ion studies may also contribute to knowledge in this field.

The observations reported here deal with the indoor characteristics of air ion concentrations and mobilities and their variation with respect to tobacco smoke pollution. A brief but general survey of previous work will be helpful in establishing a perspective for this study.

SURVEY OF BIOLOGICAL INVESTIGATIONS

For over twenty-five years numerous investigators have studied the effects of air ions upon man, other animals, microorganisms and plants. They report correlations with such diverse functions as growth rate, respiration, skin temperature, pulse rate, reaction time, mortality, and tracheal ciliary activity. A wide range of physiologic effects have been reported in the literature. They include changes in the succinoxidase activity of the adrenal gland, and variations in blood sugar, pH, pressure, sedimentation rate, and carbon dioxide capacity. The principal medical applications have been in the treatment of asthma and hay fever. In general, negative air ions are regarded as beneficial. It is claimed that air rich in negative ions brings about a feeling of relaxation and well-being. On the other hand, positive ions are said to produce feelings of irritation, depression, and fatigue, sometimes accompanied by headaches. However, prolonged exposure, as compared to periodic exposure, to either type of ion is held to be deleterious. Kornblueh (1955) gave an excellent review of the biologic effects and medical applications of ionized air. Beckett (1959) has established the import-

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ance of air ions as an environmental factor. Hicks (1957) has pioneered in the development of air ion sources and ion collectors.

It should be emphasized that most of these reports deal with effects produced by artificial air ionization at levels far above those encountered in most environments.

<center>ATMOSPHERIC IONIZATION</center>

Terrestrial radioactivity is the principal ionizing agent over land surfaces. Cosmic rays are the most important factor in the production of air ions over water and at high altitudes. Storms and waterfalls are also considered to be ion producers. Fleming (1949) discussed natural ion sources in detail. Beckett (1959) classified air ions as small, intermediate, and large. This system was utilized in the present study.

Small ions, or high mobility ions, are singly charged, gaseous complexes of several molecules. They possess a minimum mobility of about .090 cm/sec/volt/cm. In unpolluted air, small ions are the most numerous type present with about 500 to 600 ions per cubic centimeter at sea level.

Ions of intermediate size are charged complexes of several hundred molecules. They have a minimum mobility of about .030 cm/sec/volt/cm and range in size from 3 to 40 millimicrons.

Large ions are singly charged particles of low mobility ranging in size from 40 millimicrons to about 1 micron. They are commonly detected near urban and industrial centers. In the present study, the minimum mobility for large ion detection was about .010 cm/sec/volt/cm.

During periods of fair weather positive ions predominate. There are two probable causes of this effect. Most important is the apparent higher mobility of small negative ions which results in their more rapid grounding. Also, the electrical gradient between the earth's surface and the ionosphere normally results in a positive ion flow to the earth.

Although modern instrumentation has enabled the investigator to measure ion densities and mobilities with relative ease, the chemical nature of ions remains the subject of much conjecture. It cannot even be assumed that the molecules of an ion complex are chemically all the same. However, Tüxen (1936) has detected 0^- and 0_2^- in air, but no N_2^-. Martin (1954) found N_2^+ in air. He also detected both 0_2^- and 0_2^+ with the former predominating.

In a remarkable series of experiments, Krueger (1958) de-

termined that positive air ions consistently decreased the ciliary rate in the rabbit trachea (both *in vitro* and *in vivo*). Negative air ions consistently increased the ciliary rate. Using this biologic effect as an ion detector, Krueger proceeded to test various atmospheric gases. He found that nitrogen or carbon dioxide, under conditions favorable to the production of negative ions, exerted no effect on the tracheal ciliary rate. On the other hand, negatively charged oxygen produced the same effect as negatively ionized air. Under conditions favorable to the production of positive ions, nitrogen or oxygen had no detectable influence on the ciliary rate. However, positively charged carbon dioxide decreased the ciliary rate more rapidly than positively ionized air. In agreement with this, Krueger determined that positively charged air had no effect on the ciliary rate if the CO_2 content was removed. No variations in the ciliary rate (during twenty minute exposure periods) were detected for non-ionized nitrogen, oxygen, carbon dioxide or air.

The possible relationship between atmospheric ionization and pollution has interested some investigators. Beckett (1959) recorded air ion content on Rincon Hill near the San Francisco end of the Bay Bridge. He observed that intermediate ions predominated, reaching high levels during the morning and evennig peaks in traffic flow on weekdays. No such effect was observed on Saturday or Sunday. Although local authorities reported that the air was free of pollution during the test period, Beckett maintained that the high intermediate ion density was convincing evidence of contamination. In similar tests conducted at high altitudes on the White Mountains of California, Beckett observed high concentrations of small ions but intermediate ion densities were negligible.

Hessemer (1954) reported on the effects of tobacco smoke upon ion emission from hot wires, but did not investigate the effect of smoke upon air ion densities. Penney (1949) attributed some cases of wall smudging to cigarette smoke in the presence of excessive room ionization.

Krueger (1958) extended his previously described investigations to include the effects of cigarette smoke. He found that cigarette smoke alone reduced the ciliary rate of the rabbit trachea. Positively ionized air containing smoke resulted in an even greater reduction of ciliary rate. However, negatively ionized air containing cigarette smoke stimulated the ciliary rate to the same extent as negatively ionized air alone.

Beckett (1959) has reported on several sealed room tests. He found that air ion densities were lower but more uniform than

those observed outdoors. He also determined that small positive ion concentrations were generally greater than the negative.

Apparatus

Although air ion densities are relatively low (a ratio of about one ion to five trillion uncharged molecules), their detection and measurement are efficiently accomplished by recently developed equipment.

In the tests to be reported, samples of air ions at various mobilities were obtained with a Wesix Ion Collector.[2] This apparatus consists of an enclosed series of well-insulated, parallel plates and a blower for maintaining air flow. An electric heater is included to prevent moisture condensation on the insulation. The relationship between ion mobility, M, and collector plate voltage, V, is given by

$$M = \frac{d^2 v}{LV}$$

where d is the plate separation, v is the air velocity, and L is the plate length. Plate voltages of 22, 67, and 200 volts gave minimum mobility collections in agreement with the Beckett classification system. It was assumed that all small ions (and only small ions) were collected at a plate voltage of 22 volts; all small and intermediate ions at 67 volts; and small, intermediate, and large ions at 200 volts. The ion density for each class was then obtained by subtraction.

In order to calculate the ion density (in ions/cm³) by the relationship

$$N = \frac{I}{qvA}$$

(where I is the ion current; A is the area across the collector plates; v is the air velocity through the collector; and q is the charge per ion, i.e., 1.60×10^{-19} coulombs), it was necessary to calibrate the instrument by measuring the air velocity. A hot-wire anemometer was constructed and employed to measure the air velocity at several points in the collector. The average velocity of 90 cm/sec was then used in all calculations.

A Keithley model 410 Micro-microammeter was used to measure the resulting ion currents from the collector. The data were recorded by a Type 8 CE-1 General Electric Photoelectric Recorder. A Bachman Humidifier was employed in the humidity effect experiments.

THE TEST SITE

Fifty-four tests were conducted in a small vacant room (about 900 cubic feet) in a frame building located in Syracuse, New York. The room's single window and door were sealed to prevent drafts, i.e., air infiltration was reduced but the room was not pressure tight. The room was illuminated by one electric lamp on the ceiling and was heated by a hot-air wall register. The heated air was supplied by a gas furnace three stories below in the basement. The tests were conducted in March while the outside temperature was generally cold and the weather varied from clear to blizzard conditions.

RESULTS OF BACKGROUND MEASUREMENTS

Before investigating the relationship of ion densities to smoke pollution, it was necessary to measure the background densities and the possible effects of humidity variations and room heating. Thirteen background tests were conducted over a period of twelve days (Table 1). The density values were computed from ion current measurements that varied little over a period of several minutes of recording. The room temperature was usually about 70°F with a relative humidity of about 38%. The hot-air register was closed during these tests.

Table 1. Background Densities of Air Ions in a Sealed Room by Size and Charge

		Density (number of ions per cubic centimeter)							
		Positive Ions				Negative Ions			
Date	Time	Small	Inter.	Large	Total	Small	Inter.	Large	Total
3- 5-59	8:55-9:05 p.m.	331	201	432	964	213	191	482	886
3- 5-59	9:07-9:15 p.m.	274	222	390	886	213	198	475	886
3- 5-59	9:20-9:25 p.m.	274	222	390	886	177	142	418	737
3- 6-59	9:08-9:18 p.m.	390	262	423	1075	255	241	440	936
3- 7-59	11:40-11:58 a.m.	241	193	326	780	198	185	326	709
3- 7-59	4:30-4:40 p.m.	274	222	341	837	184	170	370	724
3- 8-59	2:15-2:25 p.m.	369	127	327	823	177	97	350	624
3- 8-59	7:45-8:00 p.m.	311	114	312	737	142	85	375	602
3-10-59	12:20-12:30 a.m.	213	212	284	709	71	142	358	566
3-14-59	9:45-10:00 p.m.	213	184	454	851	142	170	439	751
3-15-59	2:20-2:25 p.m.	274	222	355	851	71	142	426	639
3-15-59	2:50-2:55 p.m.	274	151	284	709	127	64	263	454
3-16-59	10:20-10:25 p.m.	170	156	269	595	99	85	241	425
Average	Densities	279	190	355	824	159	147	382	688

Although the total ion densities varied considerably, the proportions were reasonably constant. The proportions of small to intermediate to large positive ions were approximately 3:2:4. The proportions for the negative ion classes were approximately 1:1:2. Thus, the negative ion population contained a higher proportion of large ions than did the positive ion population. However, the total positive ion density was usually greater than the negative ion density by a ratio of about 5:4.

The ratio of small positive ions to small negative ions was about 3:2. For ions of intermediate size, the positive ions were in preponderance by a ratio of approximately 4:3. However, the

large negative ion densities were usually slightly greater than the large positive ion densities.

When the hot-air register was opened, the small positive ion density increased by about 100 ions per cubic centimeter with decreases of the same order of magnitude for the intermediate and large positive ion densities. Similar but smaller changes were observed in the negative ion population. The hot-air register was closed during the smoke experiments.

By use of a Bachman Humidifier the relative humidity was raised from the generally prevailing value of 38% to 50%. (The humidity was measured at the blower exhaust orifice by the wet bulb, dry bulb method.) Although recordings of ion current were considerably more variable than before, equilibrium measurements on the average did not represent ion densities significantly different from those under background conditions. It was concluded that the relatively minor changes in humidity during the smoke experiments would not be an important factor.

Effects of Smoking Upon Air Ion Densities

A series of tests were conducted in which the conditions of a "smoke-filled room" were simulated. In these experiments three volunteers were seated at a distance of about seven feet from the ion collector. During the first test they each smoked one
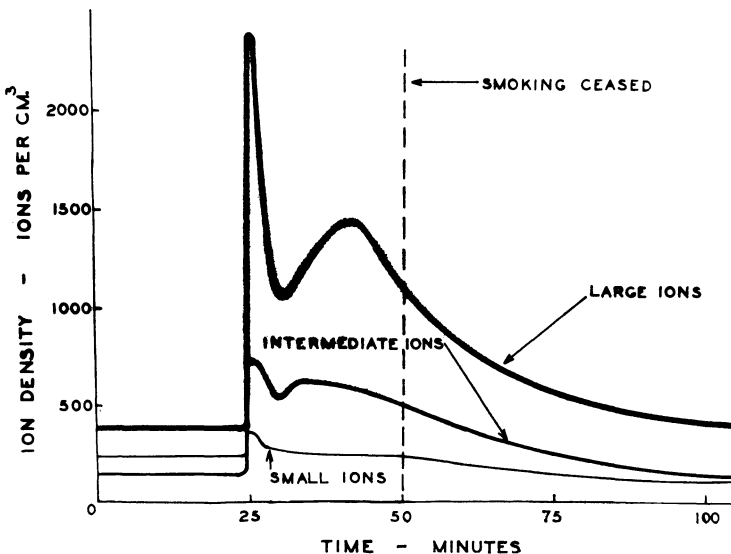

Figure 1. Ion density vs. time. Characteristic changes in small, intermediate, and large ion densities in a smoke-filled room. The plot is representative of ions of either charge. Background densities were monitored for the first twenty-five minutes. The initial peak occurred when matches were struck to ignite the tobacco.

cigar. In similar tests that followed, the atmosphere of the sealed room was filled with smoke produced by cigarette or pipe smoking. In each case the smoke was visibly quite dense. For several hours after smoking there was a perceptible haze in the air.

The variations in air ion densities were essentially the same for each mode of smoking. However, cigar smoke proved to be the most prolific ion source, producing ion densities during the smoking period that were about 33% higher than those for cigarette or pipe smoke.

The general effects of smoking upon the ion content of a sealed room are shown in Figure 1. Since both positive and negative ion densities followed substantially the same pattern of change, the graph is representative of ions of either charge.

An initial surge of ion current for all mobilities was noted when matches were struck to ignite the tobacco. The small ion densities quickly declined to a "plateau" value that remained nearly constant during the period of smoking, with the small positive ion concentrations below and the small negative ion concentrations above the background level.

The intermediate ion densities reached a secondary peak about ten minutes after lighting, with both the positive and negative ion concentrations remaining about four times higher than background during the period of smoking.

The large ion densities far exceeded those of the interemdiate or small ions during the period of smoking, with the large negative ion density slightly greater than the positive. The large ion concentrations reached a pronounced secondary peak about fifteen minutes after smoking had been initiated and remained about three times higher than the lackground level throughout the period of smoking.

After smoking had ceased, the total ion densities declined in about one hour to values slightly below that of the previous background measurements, with the large ion populations remaining in preponderance. Thus it appears that smoking in a closed room results in a persistent attrition of high mobility ions.

Table 2. Relative Densities of Air Ions in a Smoke-Filled Room

	Relative Ion Density					
	Positive Ions			Negative Ions		
	Small	Inter.	Large	Small	Inter.	Large
Background (Average) 34%		23%	43%	23%	21%	56%
During Smoking 15%		23%	62%	10%	22%	68%
One Hour After Smoking 22%		28%	50%	15%	18%	67%

The relative ion densities in a smoke-filled room are given in Table 2.

DISCUSSION

The tests results reported here are in general agreement with previous studies. The predominance of small positive ions over small negative ions was particularly noticeable. This characteristic of the ion population was verified in background, humidity, hot-air register heating, and smoking tests. Evidently, the small negative ions, because of higher mobility, move readily to ground or become attached to particles. The slightly higher densities of large negative ions that generally prevailed, in comparison to the large positive ion densities, lend further support to this view.

The apparent insensitivity of ion densities to a change as great as 12% in the relative humidity is rather suprising. Yaglou (1934) reported a definite inverse relationship between humidity and ionization.

The preponderance of large ions over small ions in the smoking experiments agree with previous observations regarding air pollution with particles. However, most of the biological studies have been concerned with the effects of small ions. Investigations of the effects of large ions upon organisms should be encouraged.

The measured variations in ion densities during smoking were probably the result of differences in mobility. The initial surge of ion current, produced only a few seconds after matches had been struck to ignite the tobacco, must have been the result of thermal ionization. The rapid response of the ion collector indicated propagation by high mobility ions. However, many of these ions had become attached to particles before reaching the collector.

Tobacco smoke is a prolific source of particles. Many of the high mobility ions already present in the atmosphere will become attached to these particles. In addition, much thermal ionization will be produced by the burning tobacco. Many of these ions will also become attached to particles. These low mobility ions will not reach the collector immediately. Thus, the test results indicated a peak in large ion densities fifteen minutes after smoking commenced. The peak in intermediate ion densities after ten minutes had elapsed is also in agreement with this analysis.

Even after smoking had ceased, an abundant supply of par-

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ticles remained in the air. Thus, many ambient ions continued to form large ions. This accounts for the persistent attrition of high mobility ions as revealed by these tests.

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