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ABSTRACT

This paper reviews current knowledge of air ions, with emphasis on the levels of indoor and outdoor ion concentration and possible physiological effects on human comfort, using naturally and artificially ionized air. There is appreciable evidence that for some clinical treatments the use of negative ions is beneficial; but there is evidence as well that the benefits for normal subjects are of very little or no practical significance.

LES IONS DANS L'AIR ET LEUR RELATION AVEC LE COMFORT HUMAIN

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RÉSUMÉ

Les auteurs examinent les connaissances actuelles au sujet des ions dans l'air, en insistant sur les niveaux de concentration d'ions à l'intérieur puis en plein air et sur les répercussions physiologiques éventuelles quant au confort des gens, en se fondant sur l'air ionisé naturellement et artificiellement. Il existe des indications appréciables que l'utilisation des ions négatifs est salutaire dans certains traitements cliniques, mais d'autres indications montrent qu'ils offrent très peu ou pas davantages pratiques aux sujets normaux.

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Since the discovery of electricity man has speculated on the effect of the electric condition of the atmosphere on his health and comfort and those of plants and animals. The freshness of mountain air and the exhilaration experienced after a storm, the oppressiveness before a storm and ill effects of hot dry wind were considered to be related to the state of electrical charges or ions in the air. Stuffiness indoors was also thought to be due, in part, to the ion content of the air, largely determined by the heating and ventilating systems and the occupants themselves.

Over the past fifty years interest in artificially altering the ion content of air for clinical treatment and human comfort has been surrounded by controversy, apparently because of the conflicting results of various studies. Although the use of ion generators in heating and ventilating systems is not common at present, a resurgence of interest occurs from time to time.

A systematic study of air ions and their biological effect on human comfort was first reported by Dessauer and his associates in Germany in 1931 (1,2). It involved tests on human subjects and had a major impact in this field. Dessauer and his associates found that air ions of opposite sign have opposite effects on both healthy people and invalids: that positive ions could cause an increase in the pulse rate, blood pressure and metabolic rate, resulting in unpleasant reactions such as headache, dizziness and fatigue; that negative ions, on the other hand, could cause a decrease in these physiological functions and produce a feeling of well-being. Such claims were naturally checked by other research workers in various disciplines (3-6), but the results were sometimes inconsistent or, under certain conditions, negative.

It is the purpose of the present paper to review, briefly, the current state of knowledge of air ions, with emphasis on the levels of indoor and outdoor ion concentrations and possible physiological effects on human comfort, using naturally and artificially ionized air.

NATURE OF AIR IONS

The nucleus of an atom contains positively charged protons. Planetary electrons outside the nucleus are negatively charged, their number balanced with the positive charge on the nucleus so that atoms are normally electrically neutral. If an atom loses an electron it manifests a positive charge or becomes a positive ion; conversely, if it gains an electron it manifests a negative charge or becomes a negative ion. In this review an ion is an atom, a molecule, group of molecules or any particle such as dust or liquid droplet that has acquired a charge (7).

Ions are formed from bombardment of air molecules by particles such as alpha and beta particles and absorption of radiation such as X-rays, gamma rays, cosmic rays or short-wave ultraviolet radiation. These sources of energy dislodge electrons to form positive ions. The electrons are subsequently captured by other air molecules to form negative ions.

Approximately half the total ionization is due to radioactive matter in the air, one third to radioactive matter in the soil, and one sixth to cosmic rays (8). Ions are continually formed and neutralized by combination with ions of opposite polarity, so that there is a fairly constant concentration of them in the atmosphere. Ionization due to cosmic rays and radioactive matter in soil is approximately constant with time at a particular location. That due to radioactive material in air is subject to variation with air turbulence and the rate of exhalation of radioactive gases from the soil, being affected by such factors as temperature, wind and ground covering.

Ions are classified by size as small, intermediate, and large (7), as well as by polarity. Their classification by size is based on the velocities of the ions in an electric field. The ratio of velocity to field strength is referred to as the mobility of the ion. Small ions have mobilities between 1 and 2 cm/sec/V/cm. They are composed of a single ionized molecule with other molecules clustered around and held together by the charge. Large ions have mobilities between 3×10^{-4} and 8×10^{-3} cm/sec/V/cm. They are made up of material particles such as dust, smoke particles and liquid droplets that are charged either through friction or by coalition with small ions. Intermediate ions are similar to large ions, except in the size of the particles, and are sometimes considered as a sub-group of the large ions.

There is a further physical difference between large or intermediate ions and small ones. If a small ion is neutralized the molecules that have been held together by the charge move apart, leaving no trace of the original collection. If a large ion loses its charge, it continues to exist as an uncharged particle.

MEASURING INSTRUMENT

Measurement of the density of air ions, either positive or negative, is usually made with an ion counter whose basic component is a condenser. The ion counter does not count the number of ions directly but collects and measures the ion current to the condenser, from which the number of ions is calculated by assuming that each ion carries a unit charge.

Figure 1 is a schematic of a typical cylindrical condenser (7). The inside diameter of the outer cylinder and the outside diameter of the inner cylinder are D and d, respectively. Air is drawn between the two cylinders at an average velocity of u. If V is the potential difference between the two cylinders, the electric intensity E at a point r from the axis is

$$E = \frac{V}{r \ln D/d} \qquad (1)$$

The time, t, for an ion with a mobility, w, to move from the outer cylinder to the inner cylinder is

$$t = \frac{(D^2 - d^2)}{8} \cdot \frac{\ln D/d}{w\,V} \qquad (2)$$

The ion is carried along by the airflow in the axial direction with an average velocity of u; for it to reach the inner cylinder, the minimum length of the cylinder should be

$$L > ut$$

or

$$u < \frac{8w\,V\,L}{(D^2-d^2) \ln D/d} \qquad (3)$$

Replacing u by the airflow rate gives

$$Q < \frac{2\pi\,w\,VL}{\ln D/d} \qquad (4)$$

Finally, the number of ions per unit volume is

$$N = \frac{i}{Q\,e}$$

where N = number of ions per unit volume
i = ion current
e = charge per ion
Q = airflow rate.

The ion current, i, is independent of V provided that V is high enough to satisfy the condition specified by Eq. (3). The ion of the lowest mobility collected depends on the dimention of the condenser, flow rate, and applied potential difference. An ion counter can therefore be designed to measure small or large ions. Either positive or negative ions can be measured by simply changing the polarity of the potential difference. A typical ion counter, which consists of two cylindrical condensers, one for measuring the small or intermediate ions and the other for large ions, is shown on Figure 2.

Another ion counter consisting of a parallel plate condenser (9) is shown on Figure 3. Simpler in design this counter is suitable for measurement of only the small and intermediate ions owing to the limitation on the applied potential difference.

ION CONCENTRATION IN ATMOSPHERE

Ion concentration in the atmosphere varies widely from place to place. As shown in Table I (10) the number of small ions varies from 200 to 2200 per cc depending on geographical location. There is normally a slight excess of positive over negative ions. On the average, the ratio of positive to negative small ions ranges from 0.9 to 1.4.

Ion concentration also shows regular daily and annual variations and changes with meteorological conditions. Studies indicate that local climatic condition is one of the most important factors affecting the small ion content in the atmosphere (11). In general, a drop in temperature and humidity is preceded or accompanied by a sharp rise in the ion content of air. Measurements in Boston (11) have indicated that high concentrations of small ions are usually observed shortly after mid-day or, in the summer months, with reference to diurnal and seasonal variations.

Heavy precipitation brings about a considerable increase in the number of small negative ions in comparison with diurnal and seasonal variations. Cloudiness, fog and other meteorological factors also have some effect on the ion concentration in air. The variations of the ion concentrations under the influences of these factors are shown in Figure 4.

In large cities the large ions of both signs dominate; in the less polluted air of the country small ions are dominant. The concentration of small ions is far greater at high altitudes than at sea level owing to stronger ultra-violet and cosmic radiation.

ION CONCENTRATION IN BUILDINGS

Ion concentration in an unoccupied room with natural ventilation is not very different from that outdoors (12). Once a

room has been occupied the small ion concentration undergoes a sharp decrease, its extent depending on the number of occupants and density of pollutants such as tobacco smoke. In either case, a decrease in the small ion concentration is always accompanied by an increase in the large ion concentration. This is brought about, in part, when small ions combine with the condensation nuclei given out with each breath (13) and with smoke particles to form large ions.
Figure 5 (14) shows the effect of occupancy on the number of small and large ions inside a room in a large research organization. It clearly indicates a rapid decrease in the small ion content and a corresponding increase in the large ion content almost immediately after the building has been occupied; a corresponding slow recovery sets in from one to several hours after the building has been vacated.

Various components of air-conditioning systems also cause variation in the ion concentration in buildings. Experiments by Kuster et al (15) established the following:

1) The ion content of air in the test room was not affected by the operation of an air-conditioning system without ductwork, provided the air washer and the electric heater were not in operation. Under this condition the numbers of positive and negative small ions were approximately 2200 and 2800 per cc, respectively. When air was forced through a long metal duct a small increase in the positive small ions in the test room was observed.

2) When an electric heater was operated, the positive small ion content in the test room increased sharply from about 2000 to 8000 per cc. The number of positive small ions was about three times the number of negative small ions.

3) If the air washer was turned on instead of the electric heater, the number of negative ions increased rapidly from about 2000 to 10,000 per cc.

These results are substantiated to a certain extent by the measurements conducted by Beckett (16) and Behounek et al (17).

EFFECTS OF AIR IONS

Clinical Studies

Summaries of studies of the therapeutic or clinical effects of air ions have been provided by Hicks (18) and Kornblueh (10,19). Kornblueh commented that the results of various investigations are not entirely consistent, and that this may be attributed to differences in the method of ion generation, dosage, or length and frequency of exposure; for example, although American and German workers usually limit ion density to a few thousand per cc, those in the USSR operate in much higher densities.

The ions used by Dessauer (1,2) were of charged magnesium oxide dust (thought to be pharmacologically inert) discharged into the room or administered to patients by means of a funnel placed over the face of the subject. The ion counts were about 10^6 ions per cc. These experiments indicated that positive ions increased and negative ions decreased respiration rate, basal metabolism and blood pressure. In most instances positive ions resulted in headaches and nausea; negative ions produced a feeling of well being. Good therapeutic results were obtained when cases of hypertension were treated with negative ions.

Dessauer's findings were supported by those of Kuster and Janitzky in 1932 (20) and by Tchijievsky and Voynard in 1934 (21). Work reported in 1937 by Herrington and Kuh (22), who employed the Dessauer technique, indicated, however, strictly negative results. Hypertensive patients were unaltered by treatment with ionized air and physiological variables were unchanged. Bierman in 1933 (23) reported good therapeutic results with negative ions for nasal infections; and Kornblueh et al (4) reported that patients suffering from hay fever and asthma found temporary relief when exposed to negative ions, although their symptoms recurred within a few minutes to two hours of returning to a normal environment.

The effects of negative ions on over three hundred patients suffering from burns were reported by Kornblueh (10) who found marked improvement in the affected areas and a somewhat shortened period of healing. In his review in 1960, Kornblueh (10) stated that the clinical application of artificially ionized air showed encouraging results but that much work remained to be done before this method could find full acceptance in human and veterinary medicine.

Studies on Normal Subjects

Herrington in 1935 (24) stated that Dessauer's data on normal subjects (1,2) are scanty and do not indicate any of the striking effects obtained with hypertensive subjects. He also considered that Kuster and Janitzky's (20) results are only suggestive. Herrington's studies (24) on eleven male subjects indicated that administration of positive or negative ions produced no changes in physiological function or subjective sensation.

Yaglou et al (25) conducted tests on 60 subjects, including 15 suffering from some affliction. They were exposed for a period of one or more hours to air containing concentrations of 5×10^3 to 1.5×10^6 small ions per cc. Outdoor air to the test room was heated to a comfortable temperature and circulated at 35 air changes per hour. No attempt was made to humidify or cool the air during warm weather. Physiological response to positive and negative ions did not appear to differ greatly. Subjective sensations were favourable with negative ions and unfavourable with positive ions. The preference for negatively ionized air was not strong enough, however, to suggest a significant improvement except for abnormal subjects. Ionized air, irrespective of sign, appeared to exert a normalizing influence upon physiological functions above or below the norm.

In 1933 Brandt (26) conducted tests on five normal subjects (once a week for over a year) in a psychometric chamber with only the temperature controlled during cool weather to between 70 and 75 °F (21 and 24 °C). No attempt was made to control humidity or temperature during warm weather; and the ventilation rate was kept at 30 air changes per hour so that the ion counts in the chamber and outdoors showed little difference owing to the rapid circulation. As the chamber was not artificially ionized, changes in ion content were those due to weather and seasonal variation. The range of small ion content during the experimental period was between 82 and 590 ions per cc. Brandt found that physiological changes appeared to be associated with changes in air ionization, but the evidence was not conclusive. Neither was there any apparent change when a subject was exposed to de-ionized air (obtained by passing air through several layers of absorbent cotton).

Studies sponsored by the American Society of Heating, Refrigerating and Air-Conditioning Engineers were undertaken by Humphreys and Jennings in 1960 (6) in an attempt to answer questions related to ions and human comfort. The tests involved sixteen subjects in a test room controlled at two different air temperatures: 78 °F (25 °C) for thermally optimal conditions, and 87 °F (30 °C) to impose a slight thermal stress. Relative humidity was controlled at 50 per cent. Ions were generated by a controlled corona discharge between a small tungsten wire and grounded electrodes. The ion counter was adjusted to record ions having a mobility of 0.05 cm/sec/V/cm or greater (small and intermediate ions). The average ion counts were about 15,000 positive ions per cc and about 5,500 negative ions per cc during the test periods (differences in concentration were due to the characteristic of the ion generator). The background ion counts were 500 positive ions per cc and 250 negative ions per cc.

Duration of each test was three hours of two of the three ionic conditions (background, positive, negative). Each subject was asked to cast votes on the degree of sensation related to thermal sensation, perspiration, pleasantness, fatigue, humidity, air motion and mood. The data were analysed using a statistical approach involving the test of the null hypothesis that for a population of normal individuals the mean ranks for the three ionization conditions (background, positive and negative) are equal. The results tended to support the null hypothesis; that is, that the ionic state of the atmosphere under the test conditions had no effect on sensation. If there is any effect on thermal sensation the results suggested that ions of both polarities tended to make one feel cooler.

The same experimental results were analysed by Koch (27), who concluded that at 78 °F (25 °C) there is no significant change in sensation except for mood, which is improved by positive ionization. At 87 °F (30 °C), four of the 15 subjects tested preferred air ionization of either polarity, two preferred positively ionized air, one preferred no ionization and eight had no preference.

SUMMARY

This literature survey is not intended to be exhaustive but to give an appreciation of the nature of ions and their effect on human health and comfort.

There is appreciable evidence that the use of negative ions for some clinical treatments (hypertension, asthma, hay fever, burns) is beneficial, but there is also evidence of no effect. The possible benefits of air ionization to normal subjects were found to be of little significance, although there were some normalizing and cooling effects. Although heating and ventilation systems and human occupancy may cause changes in the ion content of indoor air, these changes are not considered detrimental to comfort. All evidence to date appears to indicate that artificial ionization in general ventilation is not warranted.

Ion Concentration as a Possible Index of Air Quality in an Occupied Room

The review indicates that the effect of air ions on the comfort of anyone with normal health is of very little or no practical significance. It also indicates, however, that when a room is occupied the ion content of the air is affected, as indicated by an increase in the number of large ions and a corresponding decrease in the number of small ions. This phenomenon has been found to be associated with the production of large molecules from breathing and smoking (11-14), the usual sources of indoor air contaminants. Thus, by measuring the air ion content the state of air vitiation may be inferred (28). Such information may be useful in the study of air quality and hence ventilation requirements.

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TABLE I

AVERAGE LEVELS OF SMALL IONS IN DIFFERENT GEOGRAPHICAL LOCATIONS
(Reproduced from Ref. 10)

Country	Location	(Small) n+	n-	(Total) n±	n-/n+	(Large) N±
Austria	Salzburg	650	629	1.279	1.03	
Germany, East	Potsdam	775	629	1.404	1.23	
Germany, West	Munich	1.110	880	1.990	1.23	
Great Britain	Kew	440	314	754	1.40	
Ireland	Glencree Valley	580	433	1.013	1.33	
Japan	Sapoko	1.096	1.119	2.215	0.98	
Poland	Poznan (May)		309	-	-	
	(Dec.)		110	-	-	
Rumania	Baile Herculane (Spa) (July)	994	1.003	1.997	0.99	
Rumania	Black Sea coast average from six locations on Western shores	507	293	800	1.73	
Rumania	Cluj (average for one year)	543	520	1.063	1.04	
Spain	Barcelona	629	482	1.111	1.23	
Switzerland	Davos	1.236	1.006	2.242	1.23	
Switzerland	Jungfrau	1.508	808	2.316	1.71	
U.S.A.	Boston (average for two years -adapted)	288	240	528	1.2	
U.S.A.	Boston (during thunderstorm -average)	1.342	1.465	2.807	0.91	
U.S.A.	Philadelphia (May-average)	357	346	603	1.03	
	(Nov.-average)	518	490	1.008	1.06	
USSR	Jessentuki (Spa)	1.092	1.067	2.159	1.03	
USSR	Kislowodsk (Spa)	1.260	1.106	2.366	1.17	
	Kislowodsk (surroundings)	1.660 to 2.168	660 to 1.535	2.320 to 3.703	1.41 to 2.51	
USSR	Leningrad (park)	-	-	800	1.11	987
	Leningrad (Botanical Garden)	-	-	701	1.08	1.551
USSR	Leningrad (Factory #1, outdoors)	-	-	403	0.91	14.700
	(Factory #2 - outdoors)	-	-	814	1.31	11.590
	(Factory #3 - outdoors)	-	-	233	1.20	15.440
USSR	Moscow (average for one year)	927	837	1.764	1.1	
USSR	Odessa (two locations at the shore)	648	798	1.446	0.86	
USSR		689	831	1.520	0.95	
USSR	Mazesta (Spa)	1.214	1.281	2.495	0.95	
USSR	Sochy (sea shore resort)	1.270	1.067	2.337	1.1	
USSR	Ussik-Ata near Frunze, resort (altitude 1.775 m)	1.472	1.029	2.501	1.4	
	(at the river)	1.610	1.720	3.330	0.94	
	(at the rapids)	1.610	4.881	6.760	0.4	
USSR	Yalta (resort) (at the shore)	908	788	1.696	1.1	
	Yalta (annual average)	811	802	1.613	1.06	

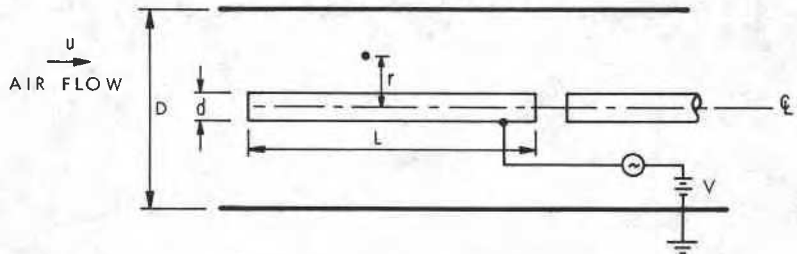
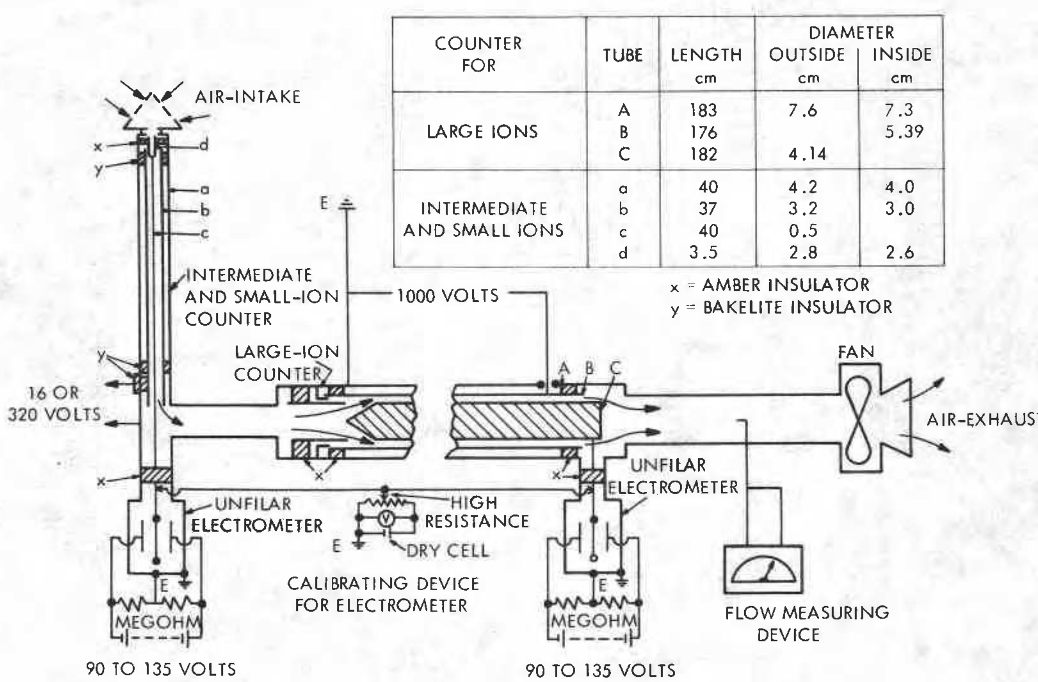


FIGURE 1

CYLINDRICAL CONDENSER



COUNTER FOR	TUBE	LENGTH cm	DIAMETER OUTSIDE cm	DIAMETER INSIDE cm
LARGE IONS	A	183	7.6	7.3
	B	176		5.39
	C	182	4.14	
INTERMEDIATE AND SMALL IONS	a	40	4.2	4.0
	b	37	3.2	3.0
	c	40	0.5	
	d	3.5	2.8	2.6

FIGURE 2

ION COUNTER (FROM REF. 7)

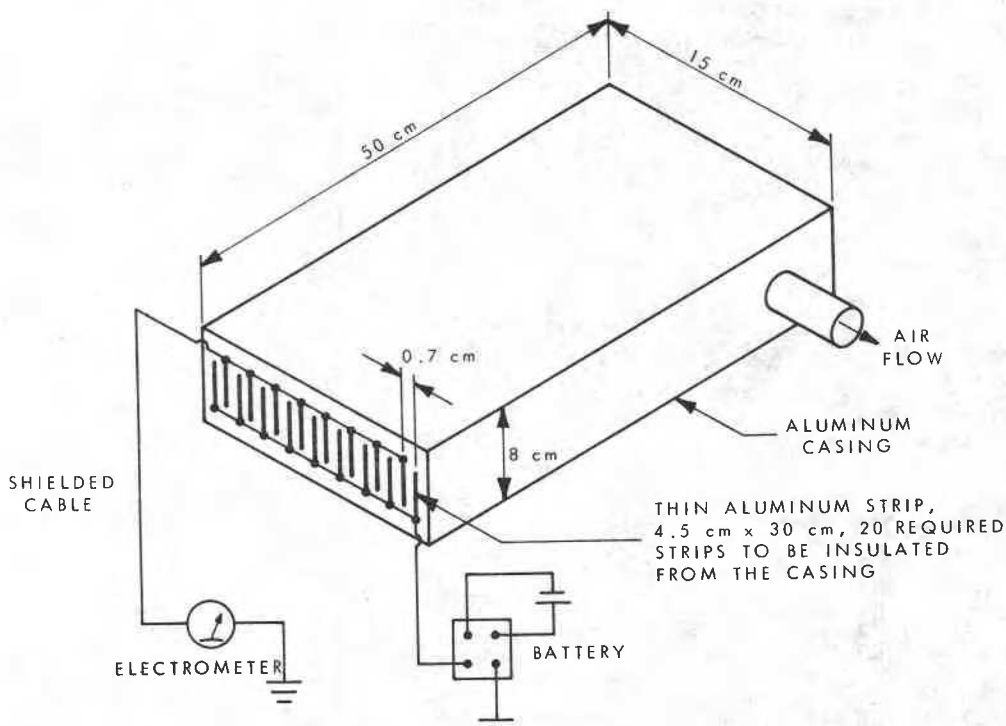


FIGURE 3

ION COUNTER (MODIFIED FROM DIAGRAM IN REF. 9)

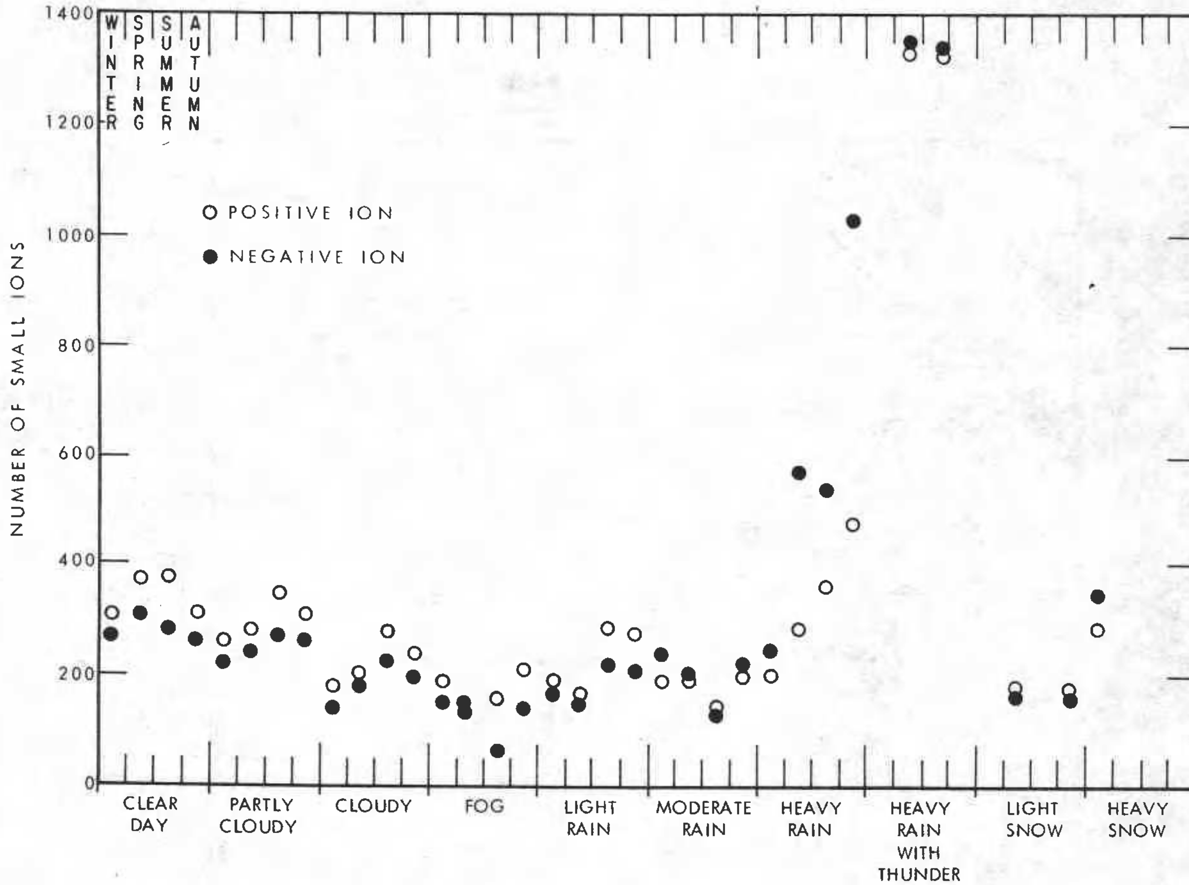


FIGURE 4

THE EFFECT OF METEOROLOGICAL CONDITIONS ON THE NUMBER OF SMALL IONS IN THE ATMOSPHERE (DATA FROM REF. 11)

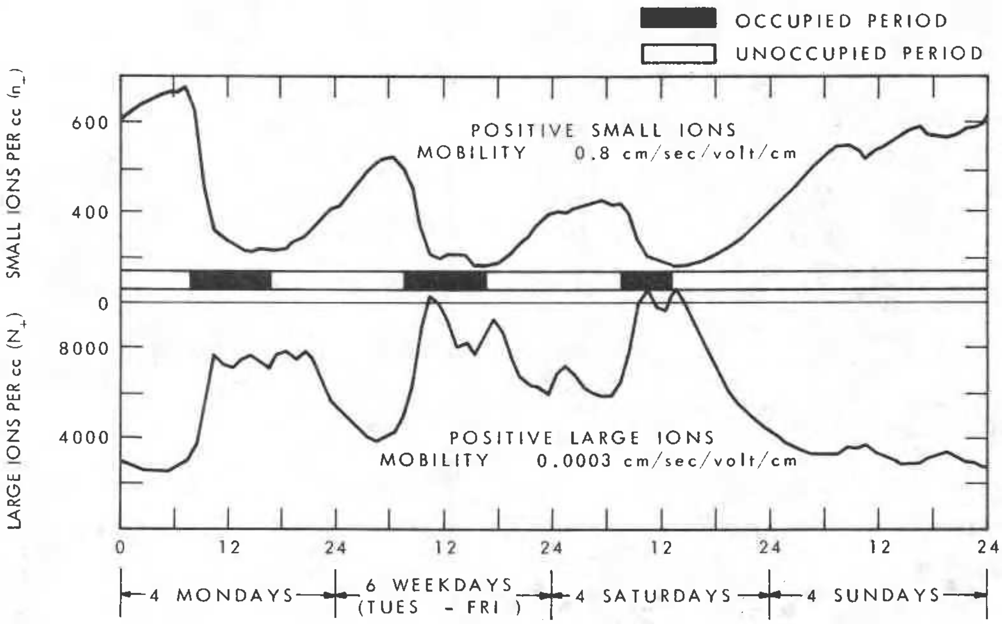


FIGURE 5

EFFECT OF OCCUPANCY ON NUMBERS OF SMALL AND LARGE IONS INSIDE ROOM 210 IN MAIN LABORATORY, DEPT. OF TERRESTRIAL MAGNETISM, WASHINGTON, D.C., NOVEMBER 17 TO DECEMBER 7, 1933 (REF. 14)