STUDY OF AIR IONS DENSITY AND ION GENERATING SYSTEM IN AN INDOOR ENVIRONMENT

BY

CHENGHONG ZHOU

A Thesis
Submitted to the Faculty of Graduate Studies
in Partial Fulfillment of the Requirements
for the Degree of

MASTER OF SCIENCE

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ABSTRACT

Air ions have been studied for many years and their possible biological effects have been recognized. The control of environment by adding artificially produced air ions is a subject widely investigated by researchers. In recent years the use of ionizers has been considered as a possible means for reducing electrostatic discharge (ESD) and particle contamination in air and on surfaces. However, the effectiveness and the efficiency of ionizers have not been studied systematically.

This thesis describes the ion density characteristics of air, studied in a controlled room. The evaluation of several types of emitters and voltage source requirements are presented. The theoretical analysis of the electric field for the sample emitter is included.The data from the experiments demonstrated that the emissivity of ionizers in the proximity of grounded materials is greatly decreased. Experiments with an air circulating fan indicated that the ionizer's efficiency increases when installed within ducts. However in this case the measured ion density fluctuated as shown by increased standard deviation. Studies showed that in a closed room the ion density depends largely on the position of the emitters.

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CHAPTER 1
INTRODUCTION

Biological and biomedical effects of air ions are still largely unknown although the subject has been studied for nearly a century. Because these effects do not immediately influence people's health and may not threaten people's life, few researchers have worked in this area, and the literature on the subject is limited. However the rapid development of industry and the resultant pollution has made it necessary to undertake systematic and scientific studies of the biological and health effects of air ions.

1.1 Air Ion Origin and Properties

Air is normally ionized to some extent as a result of cosmic rays passing through the atmosphere and of natural or man–made radioactivity in the environment.

The process of air ion formation can be explained as follows: when a high energy quantum acts on a gaseous molecule or atom it ejects an electron and the molecule becomes a positive ion. The ejected electron, if having enough energy, attaches to an adjacent molecule, transforming it into a negative ion. These positive and negative ions can be categorized into three groups according to their sizes and mobilities: small, intermediate and large ions.

Small ions consist of charged clusters of molecules of atmospheric gases with 0.001–0.003 μm diameter and have an electric charge per ion of $1.59 \cdot 10^{-19}$ coulomb. Their mobilities are higher than $1.5 \cdot 10^{-4}$ m^2/Vsec. On the average there are about 500 negative and 600 positive small ions in 1 cm^3 of air, which contains a vast number of ordinary molecules ($2.75 \cdot 10^{19}$) in 1 cm^3. They decay within a few seconds depending upon the purity of the air, the purer the air the longer they survive [20].

Intermediate and *large ions* are larger clusters of 0.003–10 μm diameter with a slower mobility 10^{-6} m^2/Vsec or less. They are sluggish ions with charges attached to dust particles, smoke, and moisture particles. Their properties can also vary with climate and location. Also small ions colliding with and attaching to neutral aerosols can become large ions. In places where the atmosphere is polluted by dust and products of coal combustion, large ions are more frequent than small ions. Values of 50,000 large ions/cm^3 are common near towns [20].

Various studies have been carried out over many years to investigate the effects of atmospheric ions. It has been known that an excess of ions in the air, whether positive or negative, has demonstrable biological effects.

1.2 Effect of Air Ions on Animals and Human

Numerous biological effects of ions on animals have been reported, including the changing of serotonin levels in the brain and the blood stream. "Serotonin", 5–hydroxytryptamine or 5–HT, is a very powerful and versatile neurohormone. It is concerned with the transmission of nervous impulses and occurs in considerable quantities in the lower midbrain, where it plays an important role in such basic patterns of life as sleep and mood [24]. Krueger and Reed [24] found that negative air ions reduced the amount of free 5–HT normally present in the tracheae of mice and rabbits. By exposing grinea pigs to negative ions and collecting all the urine they observed a considerable increase in the amount of 5–hydroxyindoleacetic acid, an inactive product of the oxidation of 5–HT. Their conclusion was that negative ions lower tissue levels of 5–HT by accelerating the enzymatic oxidation process.

Olivereau and Lambert [1] conducted experiments to test some aspects of learning and memory of rats and mice subjected to ionization in a chamber. To investigate the effects of negative and positive ions simultaneously, the mice were divided into three groups. One group received excess of negative air ions whereas the second received excess of positive air ions; a third group served as control. The air ion concentrations used in both positive and negative treatments were in the range of 600,000–650,000 ions/cm^3. The temperature was 23^0 C and the relative humidity (RH) was 60–65 %. The whole experiment was based on pain test and electric shock. For the pain test, a heated copper plate maintained at constant temperature 64^0C was used. The mice were dropped onto it. The time of first dropping and escaping from the plate was recorded to see how air ions affect learning. During the electric shock test, the floor of a dark room was made up of a metallic grid to deliver electric shock. The mice were put into this room. Afterwards the mice were put back to their cage which had a hole to an adjoining dark room. The tendency of the mice to return to the dark room was observed to see whether the short and long term memory is affected by the air ion treatments. The results showed that negative air ions tend to improve learning, while positive ions cause disturbing effects and retard learning.

B. Robinzon et al [27] studied the effects of negative and positive air ions on the chicken tracheal surface. Their conclusion was that neither positive nor negative air ionization affected the number of bacterial foci on the tracheal surface. However, while positive air ions increased the amount of mucoid material in the trachea the negative ions reduced it drastically.

Several reports suggested that negative ions can be used in medical treatment of people. Israel Amirav [28] studied the effects of negative ions on children with exercise induced asthma. The results of his study indicated that inhaling ionized air can reduce exercise–induced asthma because negative ionization of air reduces serotonin levels and thereby lessens bronchoconstriction after exercise. R. Gualtierotti [29] observed the influence of ionization on endocrine glands. When endocrine glands were exposed to ions an increase in diameters and the volume of the nuclei of the cortex resulted, denoting a stimulating effect of the air–ions. St. Michajlov et al [30] investigated the use of artificial air ionization as a therapeutic means. Thirty people with bronchial asthma and 83 with hypertensive disease were treated with a concentration of 5000–15,000 negative air ions/cm^3 for 3 hours. After 20 treatments the asthmatic attacks were reported to have completely disappeared in 29 asthmatic patients, the vital capacity and forced expiratory volume increased by an average of 337 ml, and 405 ml, respectively, and the diffusion capacity improved by 9%. Those with hypertensive diseases were said to have felt much better or to have been completely healed. Igho H. Kornblueh et al [34] conducted an experiment using negative ions in treatment on pollinosis, a hay–fever. They reported that with a negative ion treatment 62.9% of patients showed partial to complete relief, whereas only one of the 15 persons exposed to natural ions level showed improvement. Positive ionization gave no relief.

Winsor and Beckett [20] found that positive ions brought a dry throat, husky voice, headache and obstructed nose. Negative ions did not cause such effects. Palti et al. [20] performed 41 experiments with positive and negative ions on 19 infants, 13 of whom were suffering from asthmatic bronchitis and/or bronchopneumonia. Treatment with negative ions was said to have induced relaxation of the smooth muscle of the bronchi and to relieve tachypnea. Exposure of normal infants to positive ions induced tachypnea and spasm of the bronchial tree; the symptoms were relieved by treatment with negative ions.

Several reports show that the polarity of an air ion may affect weather–sensitive people. By studying a well–known wind, sharav, hot dry winds from dessert, F. G. Sulman et al [31] found that sharav produces increased ionization in the atmosphere, values for positive and negative ions going up from an average of 1,000 to 1,500 ions/cm^3. Most of these ions are the positively charged small ions. F. G Sulman conducted a further study in 1980 [32]. He claimed that weather migraine is mostly due to serotonin release and that migraine due to positive air ionization, especially weather migraine, is best prevented by negative air ionization. Many people are suffering from unnecessary drug consumption such as sleeping pills, tranquilizers and pain killers. These drugs may induce negative side effects. From many years of repeated tests, F. G. Sulman [33] recommended that negative ions can be substitutes for drugs because use of negative air ionization reduces nervous reactions.

1.3 Clean Room Applications

Recently the use of room ionization has been considered as a possible means for reducing ESD (electrostatic discharge) and particle contamination in air and on surfaces. In the electronics industry accumulation of electrical charge on products can cause a buildup of high static potentials and damage to electronic circuitry. It can also cause contamination on the devices. Therefore the electrostatic potentials can influence the yield and reliability of the electronic devices. Ion–generating systems are used to neutralize the electrostatic potentials built up on the surfaces of the electronic device.

Huffman et al [25] studied this subject, by applying 5 kV to four isolated wafers of electronic devices every hour for 24 hours, the number of different size of particles on the wafer was recorded with and without the ion system. Ionization was produced by supplying a approximately two hertz potential of approximately 9 KV to the emitter pins, each emitter pin generates both positive and negative ions. A number of one–micron diameter particles was observed in different positions of the wafer. Fig.1.1 shows that with the ion generating system the number of particles on the wafer are significantly decreased.

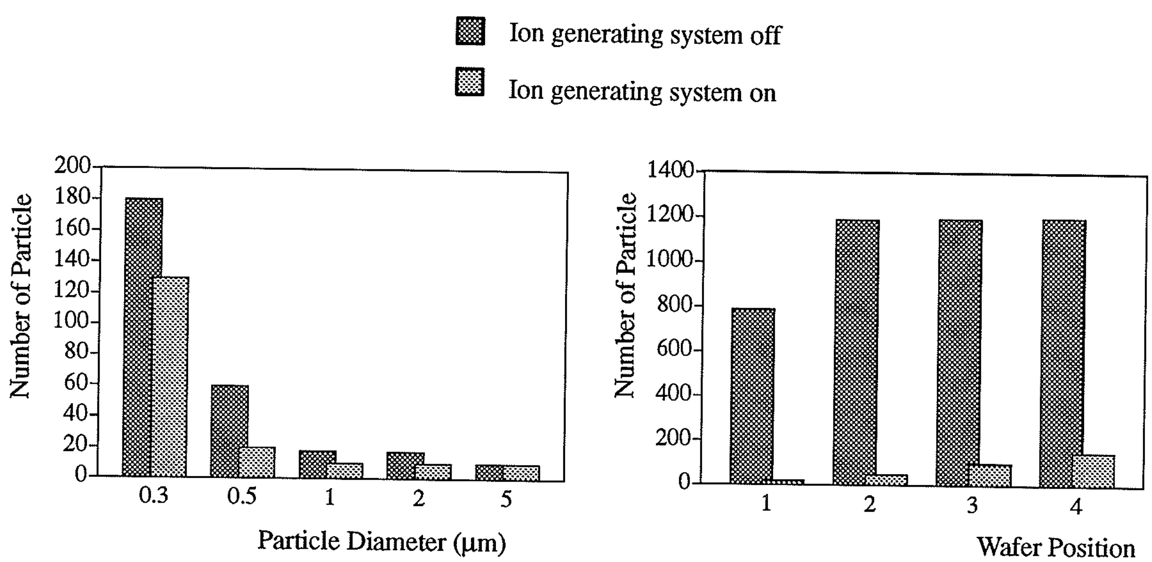


Fig. 1.1 Relations of Number of Particles, Particle Diameter and Wafer Position with and without Ion Generating System [25], Copyright by EOS/EDS Synoisuyn Proceedings

Environmental tobacco smoke in public buildings is currently of great interest. Passive smoke is not merely a nuisance to office colleagues. It may cause eye irritation, headaches, nasal symptoms, and coughing [21]. The smoke particles have rich components. By using a negative ionizer the indoors air solid pollutants such as cigarette smoke, dust, soot, industrial pollutants, pollen, smog (created by traffic pollution, etc.) are precipitated to ground due to electrostatic attraction. Thus, an air ionizer acts substantially as a slow electrostatic precipitator reducing the number of airborne particles.

James L. Repace et al [19] conducted experiments designed to investigate the efficiency of negative ion generators for removing ambient tobacco aerosol from typical indoor spaces. The decay of tobacco aerosol was drastically increased in the presence of negative ionizer as shown in Fig.1.2.

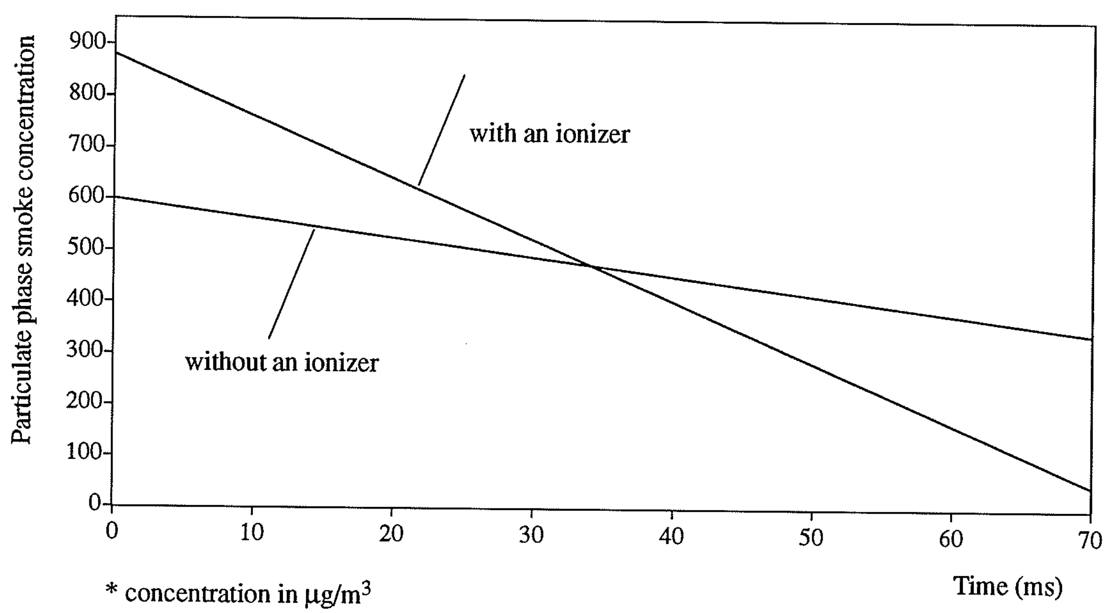


Fig. 1.2 The Decay of Aerosols with Four–emitter Ionizers in a $69.9m^3$ Unventilated Room Contaminated with Cigarette Smoke [19], Copyright by Clinical Ecology

They concluded that the negative ion generator is an effective device for the removal of the particulate phase of ambient tobacco smoke, producing increments in the natural removal rate in unventilated rooms of real–world dimensions, ranging from 3:1 to 18:1 enhancement.

1.4 The Sick Building Syndrome

The sick building syndrome is gradually attributed by some researchers to an imbalance between small positive and negative ions. Gavin Hamilton et al [17] have studied this subject. Fig. 1.3 and Fig. 1.4 summarize their data.

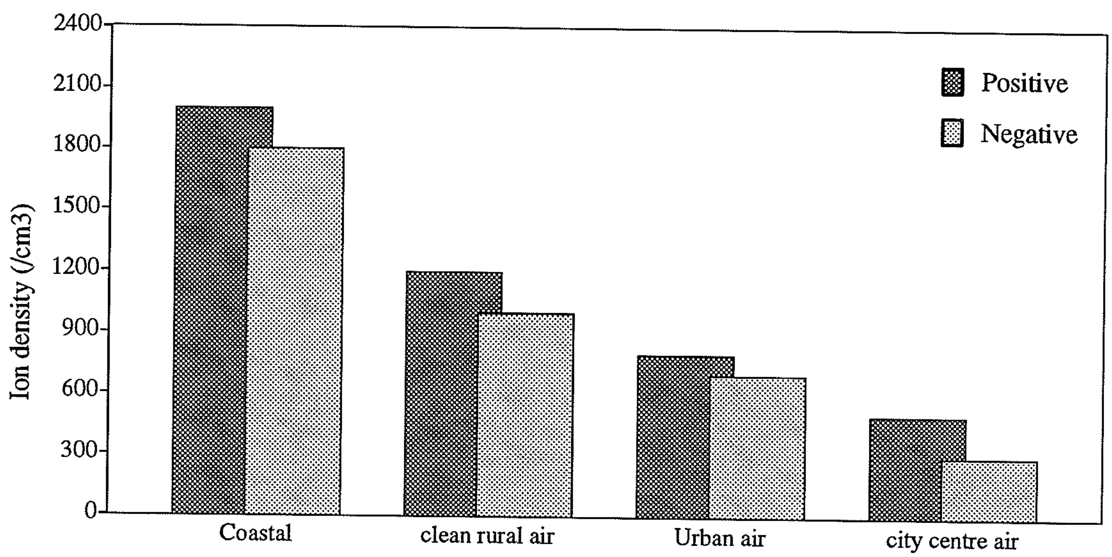
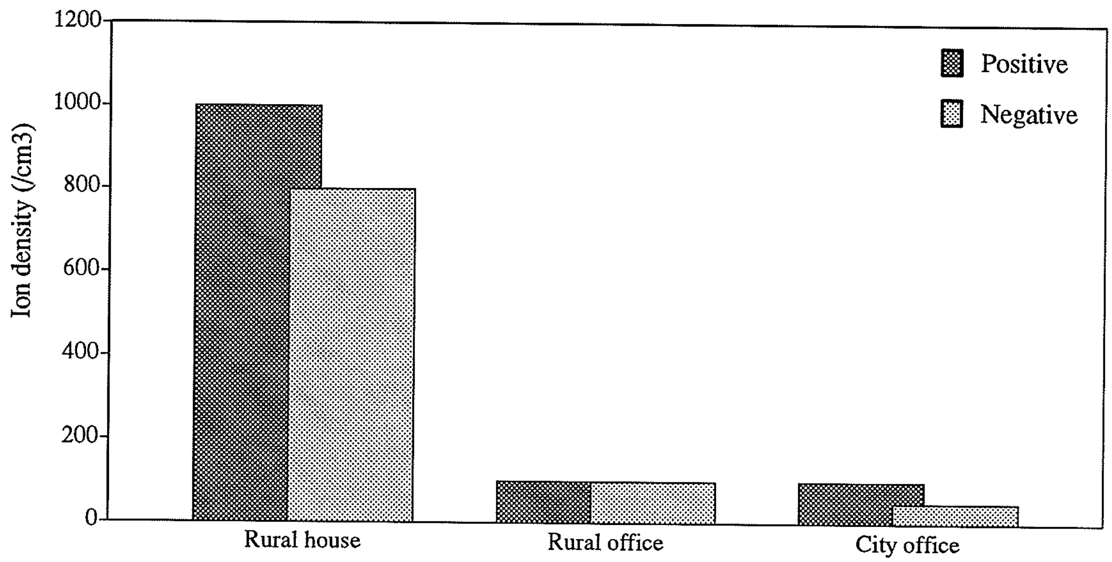


Fig. 1.3 The Comparison of Positive and Negative Small Ion Densities in an Outdoor Environment



* The two offices are with air condition and the rural house is without air condition

Fig. 1.4 The Comparison of Indoor Positive and Negative Small Ions

These figures show that the number of negative and positive small ion in coastal, clean rural air and inside a rural house are approximately equal. However the number of negative small ions is drastically decreased in city office and city center air. The paper cited several possible reasons for the decreasing ratios of negative and positive ion, e.g. the grounded metal ducts may rapidly remove negative ions and man–made fibres and materials may affect negative ion density due to high electrostatic charges. This may lead to a “sick building syndrome”. Some researches demonstrated the benefits of negative ion healing of “sick building”, whereas others have been inconclusive because of possible confounding psychological effects.

1.5 Objectives of the Research and Procedure

Technological air ionizers have been used not only in research but also in commercial applications. Biological effects of ions are being gradually accepted. In some industrial environments the level of dust and airborne particles may exceed the health–Occupational Exposure Limits (O.E.L) of 5 mg/m^3. With ion–generating systems it is possible to control electrostatic discharge (ESD) and to aid in the control of particulates in the clean room environments. As a result, some manufacturers offer ion–generating systems of various designs and configurations for industrial, food processing, hygiene and other commercial markets. However, the characteristics of ion–generating systems have not been studied systematically. Theoretically, the ion distribution dependents on (i) the applied high voltage stress; (ii) the position of the emitters; (iii) the configuration of the emitters; and (iv) the emitter materials. These parameters largely influence the effectiveness and efficiency of emitter performance.

To determine these various parameters experimentally the research described in this thesis was designed to investigate the ion distribution and ion concentration under an emitter in an indoor environment. Requirements of the high voltage source of the ion–generating system were studied. Different shapes and materials of the emitters were taken as the samples. Their ionic emissivity was characterized graphically and comprehensively from experimental data. A comparison of these emitters and theoretical analysis of their performance are presented.

1.6 Organization of the Dissertation

After the literature review on the ion density properties and ionizer usage in Chapter 1, the apparatus for the research is described in detail and their usages are introduced in Chapter 2. Ion–density characteristics of emitters in indoor environment are investigated, the data are presented graphically and discussed in Chapter 3. Chapter 4 presents graphically data on the emissivity of emitters with different shapes and materials. The measured ion density and the relative standard deviation are compared. Chapter 5 gives a theoretical explanation of the operation of an ionizer. Electric field distribution for a sample emitter is calculated. Finally, in Chapter 6, conclusions from the research and suggestions for further studies are given.

CHAPTER 2
IONIZATION SYSTEM AND MEASUREMENT APPARATUS

In the experiments, the main equipment included a negative direct current high voltage power supply, ion counters, an electrometer and a digital data taker.

The arrangement of the measuring system is shown diagrammatically in Fig. 2.1.

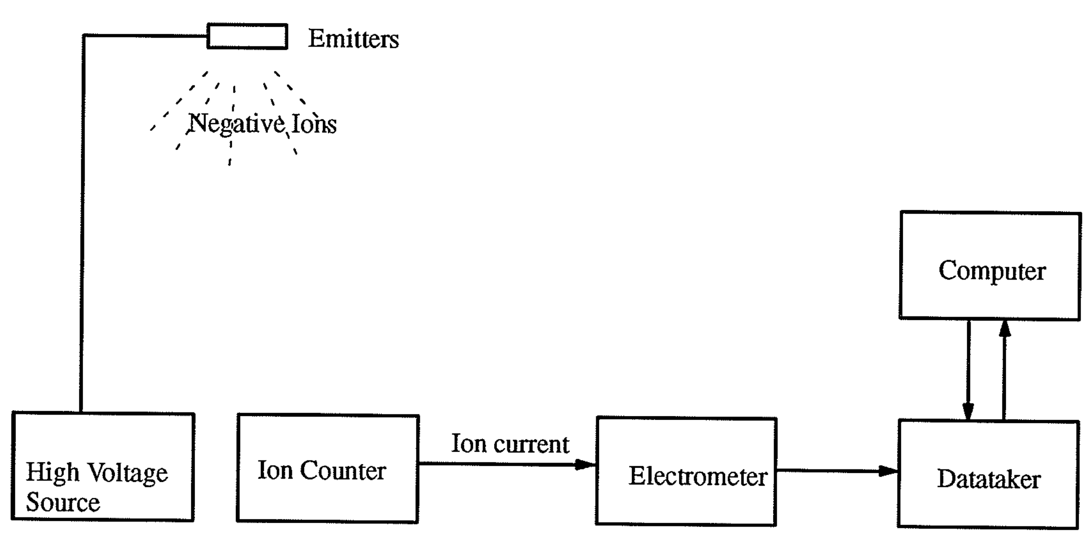


Fig. 2.1 Arrangement of Apparatus in the Experiments

2.1 High Voltage Source

The high–voltage source consisted of a three–stage doubler high–voltage generator as shown in Fig. 2.2.

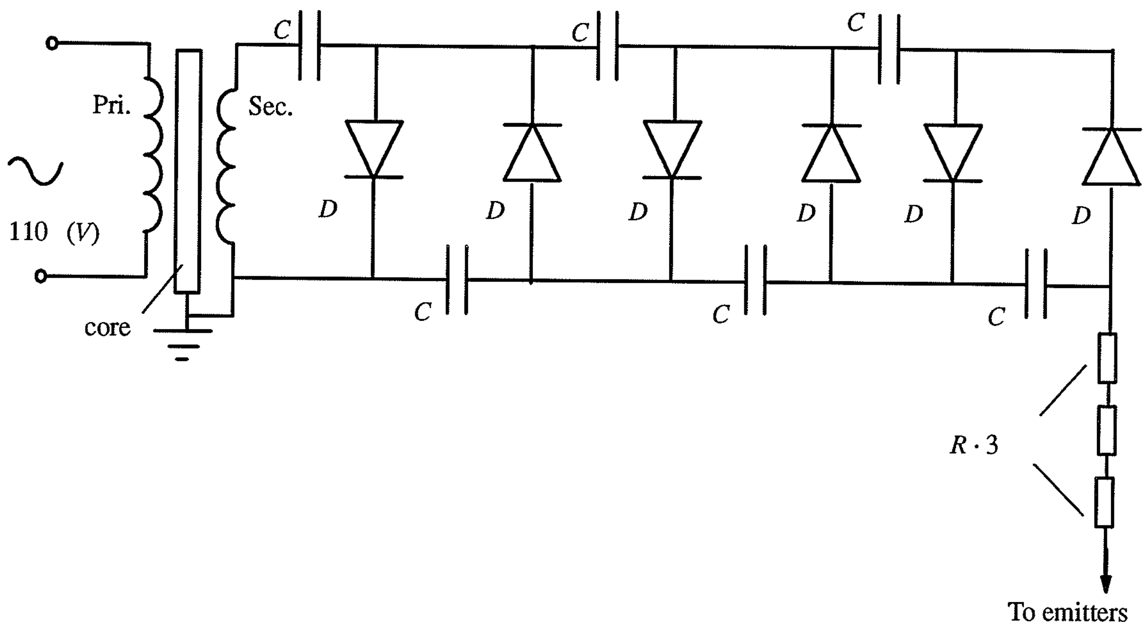
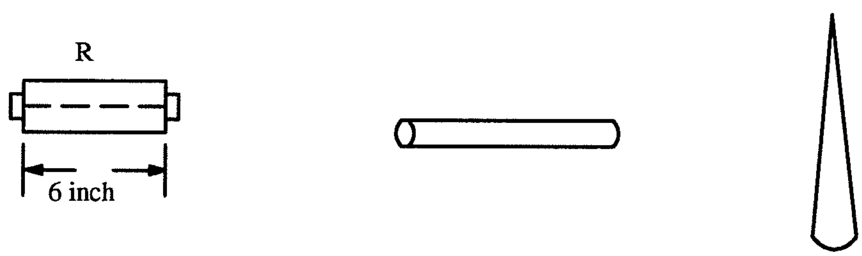


Fig. 2.2 Negative DC High Voltage Source

The rms AC voltages of the transformer are 110 V on the primary side and 1 KV on the secondary side. The output of the three stages gives a 8.5 kV DC voltage for the ion generating system. For safety the resister R connected to the last stage is in the range of 100 megohms. The core of the transformer is grounded.

2.2 The Emitters Studied

Several types of emitters shown in Fig. 2.3, used singly or in series–parallel arrangement, have been studied. Emitter #1 is made of carbon fibres and has a plastic encasement. The number of fibre sections determines the ion density generated. Emitter #2 is made of a straight fine wire. The ion emissivity was measured for wires of different diameters and for multiple wires connected in series. Emitter #3 was a steel needle. The ion densities for different sharpness of the needle were recorded.



#1 Carbon Fibre

#2 Fine wire

#3 Sharp needle

Fig. 2.3 Emitters Studied

2.3 Ion Counter

A parallel–plate type ion counter manufactured by DEV Industries Boulder, Colorado shown in Fig. 2.4 was used through out the studies.

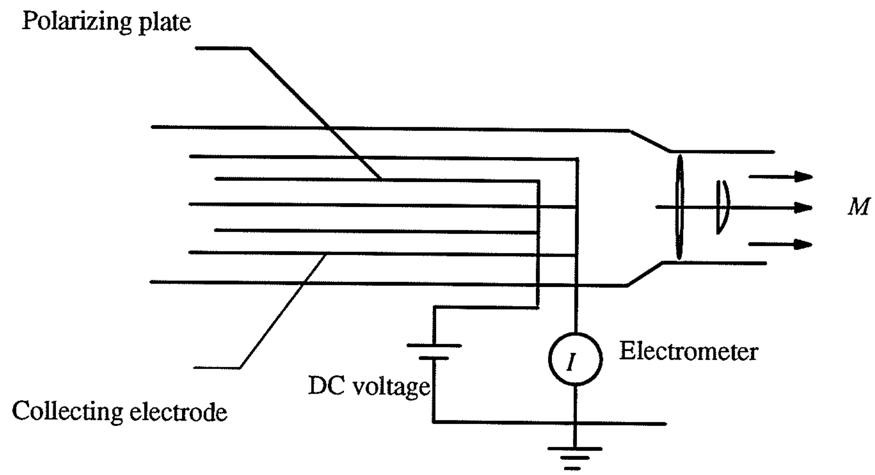


Fig. 2.4 Cross–section of a Parallel–plate Type Ion Counter

An electric motor–driven blower (M) draws ambient air–containing ions through the instrument between two sets of parallel polarizing plates and collecting plates which are arranged in a rectangular assembly. The collecting plates are grounded through a very sensitive electrometer. A DC voltage of desired polarity and magnitude is applied to the polarizing plates. The applied voltage is of the same polarity as the ions being measured.

The potential difference between the polarizing plates and the collecting plates establishes an electrical field which will exert a deflecting force on an ion of the same polarity towards the collecting plates as it enters the electric field region. All the ions with the same polarity as the applied voltage are attracted to the collecting plates as shown in Fig. 2.5.

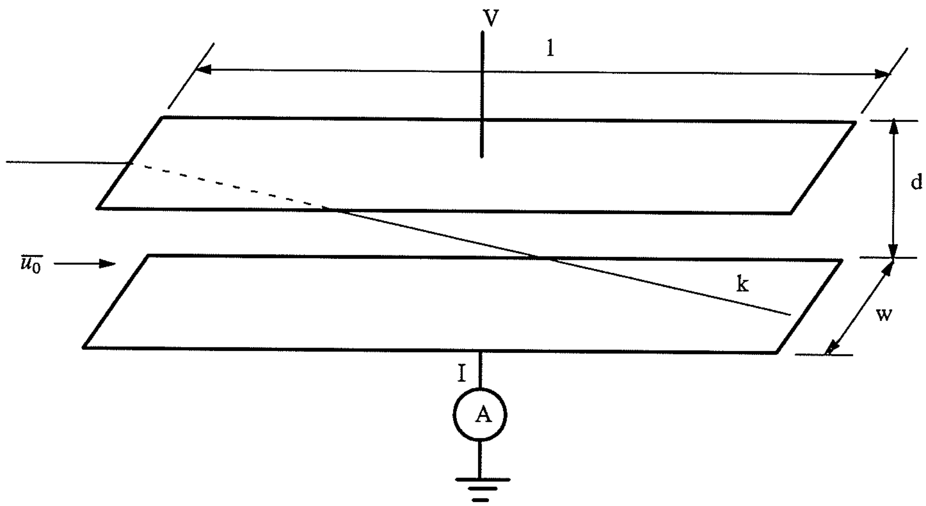


Fig. 2.5 The Operational Principle of Ion Counter

Assuming that u_0 is the air flow speed which is also the horizontal speed of ions in the ion counter, k is the mobility of ions, d is the distance between the polarizing and collecting plates, l is the length of the collecting zone, and V is the applied voltage, then the electric field strength is $E = \frac{V}{d}$, the vertical ion speed is $u_v = kE = \frac{kV}{d}$. The time needed for an ion to leave the collecting zone is $t_0 = \frac{l}{u_0}$. During this time the vertical displacement of the ion is $D = u_v t_0 = \frac{kVl}{du_0}$. If $D \geq d$, or $\frac{kVl}{du_0} \geq d$, the ion has reached a collecting plate before it could leave the collecting zone. If we define the critical mobility k_c as:

$$k_c = \frac{u_0 d^2}{lV} \qquad (1)$$

It is clear that all the ions with mobility greater than or equal to the critical mobility will be collected by the collecting plates. As the ion reaches a nearby collecting plate it gives up its charge to the collecting plate. The collection of charges from numerous ions creates a minute electric current which can be measured by an extremely sensitive electrometer. In order to obtain an electric current readout (in pA) there are specially shielded lead cable, terminating in UHF connectors, which connect the collecting plate assemblies to a picoammeter or electrometer. Any picoammeter or electrometer capable of measuring 10^{-13} A can be used. The concentration or number of ions per cubic centimeter is determined by the following equation which converts the electrometer reading into ion concentration:

$$I = q u_0 A = qM \tag{2}$$

$$N = \frac{q}{e} = \frac{I}{e u_0 A} \tag{3}$$

where q is the monopolar space charge density. u_0 is velocity of air flow through the collecting zone (in cm/sec). qu_0 is ion current density at the entrance of the collecting zone. A is the effective entrance area in cm^2. M is the laminar volumetric flow rate of air through the ion counter in cm^3/s. I is ion current (electrometer reading) in amperes. N is the number of ions per cm^3. e is the electron charge ($1.6 \cdot 10^{-19}$ Coulombs). The conversion assumes that ions carry single charges.

Since ions vary in sizes and masses they have different mobilities. By setting different critical mobilities, categorization of ions according to their mobilities is possible. For a given equipment d, l and u_0 are fixed, the changing of the applied voltage to the desired polarity and value results in suitable k_c. Ideally all ions entering the ion counter with mobility greater than k_c will be collected by the collection plates. Higher voltages on the polarizing plates would naturally cause ions of all sizes to be collected with a mobility higher than the critical mobility. This means that small ions of high mobility would be mixed with larger ions of low mobility. To separate the measurement of small ions from those of medium and large ions, the ion counter utilizes two sets of collecting plate assemblies. A shorter set used for collecting small ions is mounted in front and a longer set used for collecting medium and large ions to the second set of plates as shown in Fig. 2.6.

The critical mobility factor at the first collecting plate is less than that of the small ions but larger than that of medium and large ion so that no medium or large ions will be attached to the first collecting plate.

During the experiments, two ion counters, Beckett type and 134B type were used for comparison. The 134B ion counter measures ion concentrations in full of 1000, 5000, 50000, 250000/cm^3 of both polarity. Its measurement takes into account both the small and intermediate ions. The Beckett ion counter has 6 ranges corresponding to small, intermediate and large ions for both polarities.

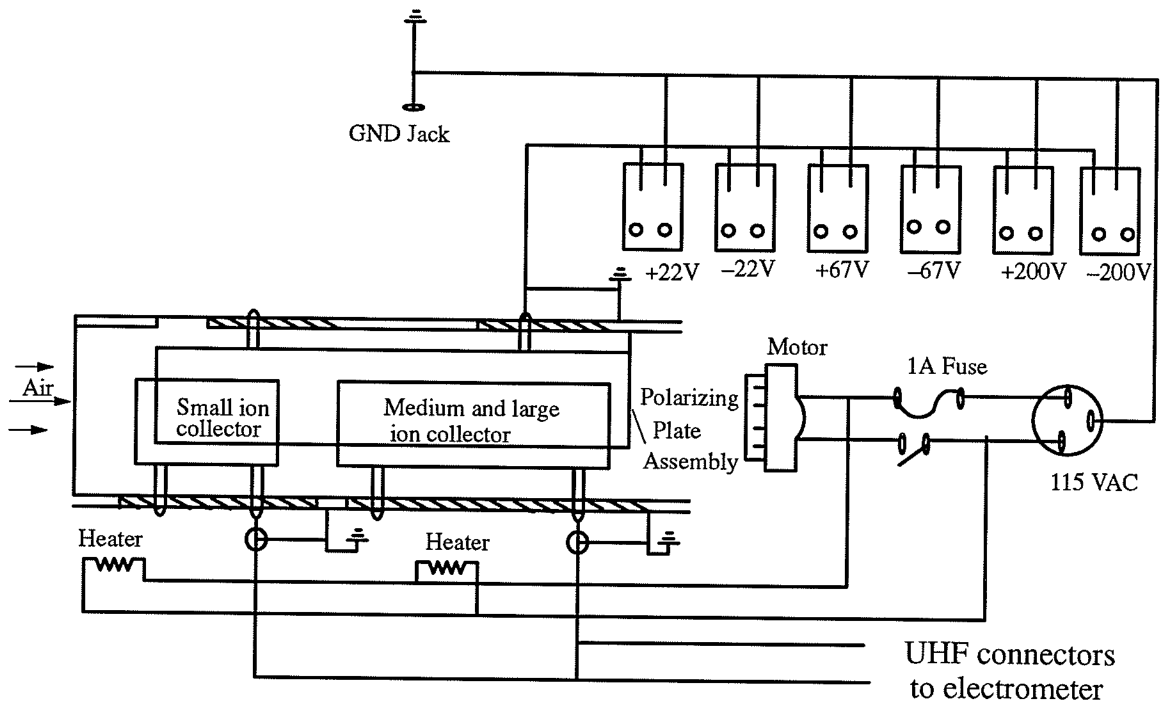


Fig. 2.6 Ion Counter Configuration, Copyright by DEV Industries Boulder, Colorado

2.4 Electrometer

The electrometer employed was Model 614 electrometer manufactured by Keithley Instruments Inc. which has a sensitivity of 10^{-14} A. It is equipped with an internal feedback to get accurate current measurement, minimizing the problems of the leakage resistance. It has a digital display and automatic polarity change over. The measurements are converted to an analog output with a scale of 2V for full range. The output impedance is 10KΩ. During the experiments the electrometer output was connected to a data taker which records the data automatically.

2.5 Datataker 50

The Datataker 50 selected for this work is an automatic data collecting device with five differential or ten single ended analog input channels. The Datataker 50 can be supervised, programmed and remotely controlled by an IBM PC (or compatible). The function of the Datataker 50 is shown in Fig. 2.7.

After being amplified, the analog signals are converted into digital signals by an analog to digital convertor (ADC). Then a microprocessor 64180 processes the coming signals. The Datataker 50 can scan for voltage, current and a wide variety of physical parameters such as temperature, pressure, flow rates etc. The real–time clock records the scanning time. The analog input signals are converted, at given intervals, into digital signals with 14–bit resolution. This high degree of resolution allows the Datataker 50 to be able to record very small signals with high accuracy. The ADC also automatically changes range over three decades of ±25.000 mV, ±250.00 mV and ±2500.0 mV. The conversion ranges for analog input signals are automatically selected. However the type of the input and the time interval between recordings need to be specified. An communication port (RS232) connects the ADC output to a computer.

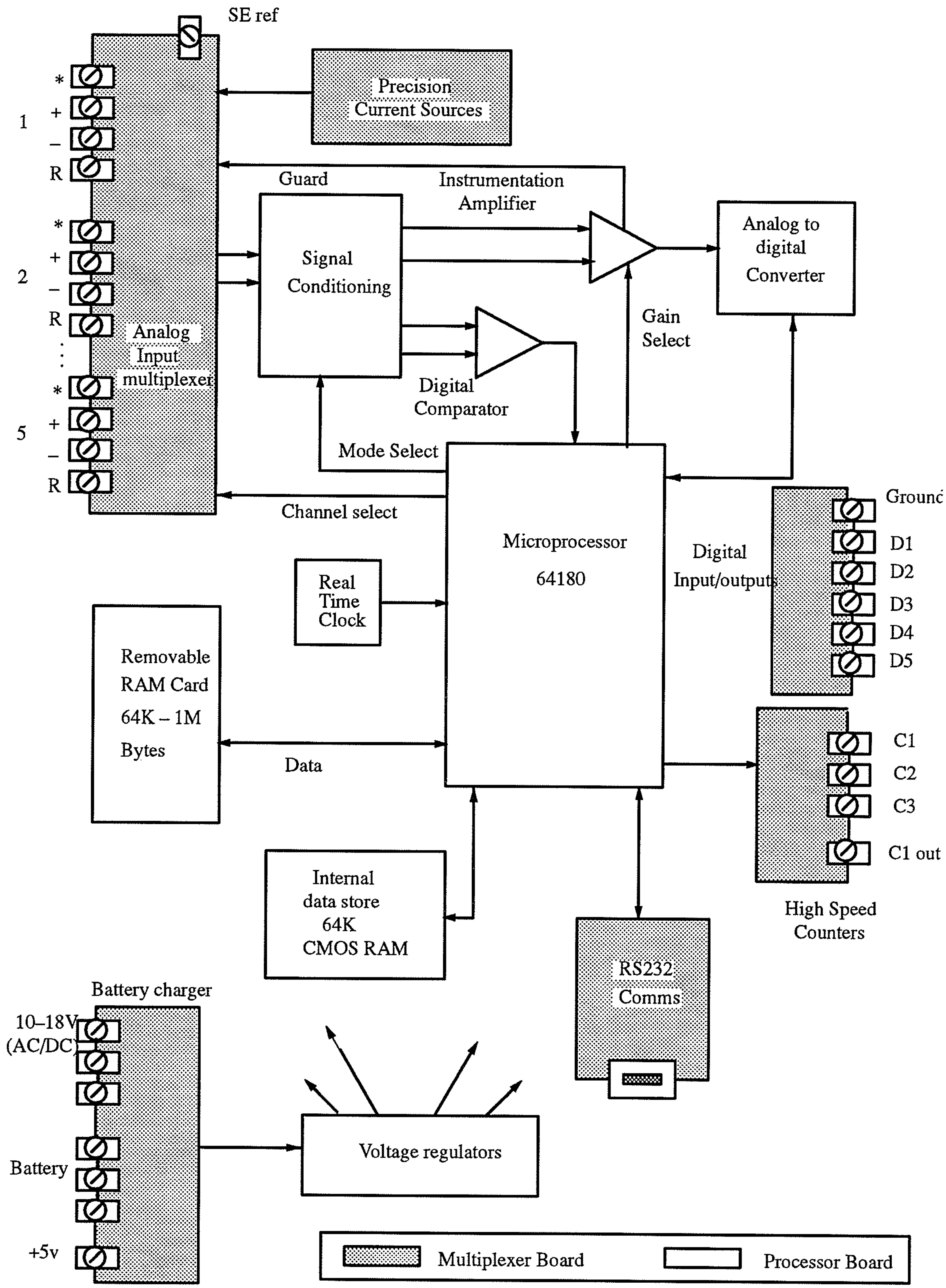


Fig. 2.7 Datataker 50 Function Block Diagram, Copyright by 1990 Data Electronics (Aust) Pty. Ltd

The Datataker 50 has an internal memory with a capacity of 64 Kbytes, which can store approximately 17,745 readings. All data is stored with full precision over the range of ±1.0e–18 to ±1.0e18. By programming the Datataker 50, when the memory is full the data can be either dropped automatically or rewritten into the beginning of the memory. A removable RAM card (64Kbytes–1Mbytes) can be installed if needed.

2.6 Decipher

A computer program *decipher* was used to control the operation of the Datataker 50 — to take the data, to record time and to store the data in the Datataker 50's internal memory. Its function is shown in Fig. 2.8.

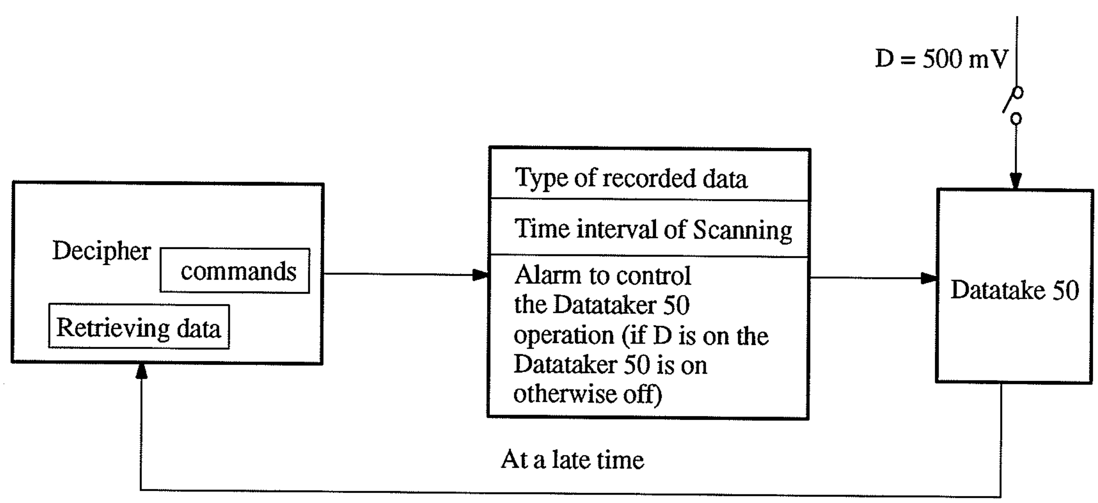


Fig. 2.8 The Function of Decipher in the Research

The Datataker 50 operates under the command of the *decipher*. The *decipher* program specifies the type of data to be recorded, the time interval of scanning and the alarm to start the Datataker 50 under given conditions. Three single–ended analog input channels were used. One is connected to the electrometer analog output to record the ion current. The second is connected to a temperature sensor to measure the room temperature. The third is connected to a 500 mV DC voltage to control the Datataker 50 by the *decipher*'s alarm command. When the 500 mV DC voltage is disconnected, the Datataker 50 stops taking data. When a computer is connected with the Dataker 50, the data can be displayed on the screen simultaneously during the logging. Alternatively the computer can be disconnected, the data is then stored in the internal memory of the Datataker 50 and retrieved by the *decipher* at a later time.

2.7 The Utility Program

For convenience, it is preferable to store the data of several tests in the internal memory of the Datataker 50. These data will then be retrieved as one large file which has to be separated into several files corresponding to each test.

The readings from the ion counter are currents in *pA*. These have to be converted to number of ions per cubic centimeter.

Computer software Lotus–1–2–3 was used to calculate the mean ion density and standard deviation. Thus it is necessary to convert the data file to a form compatible with Lotus–1–2–3.

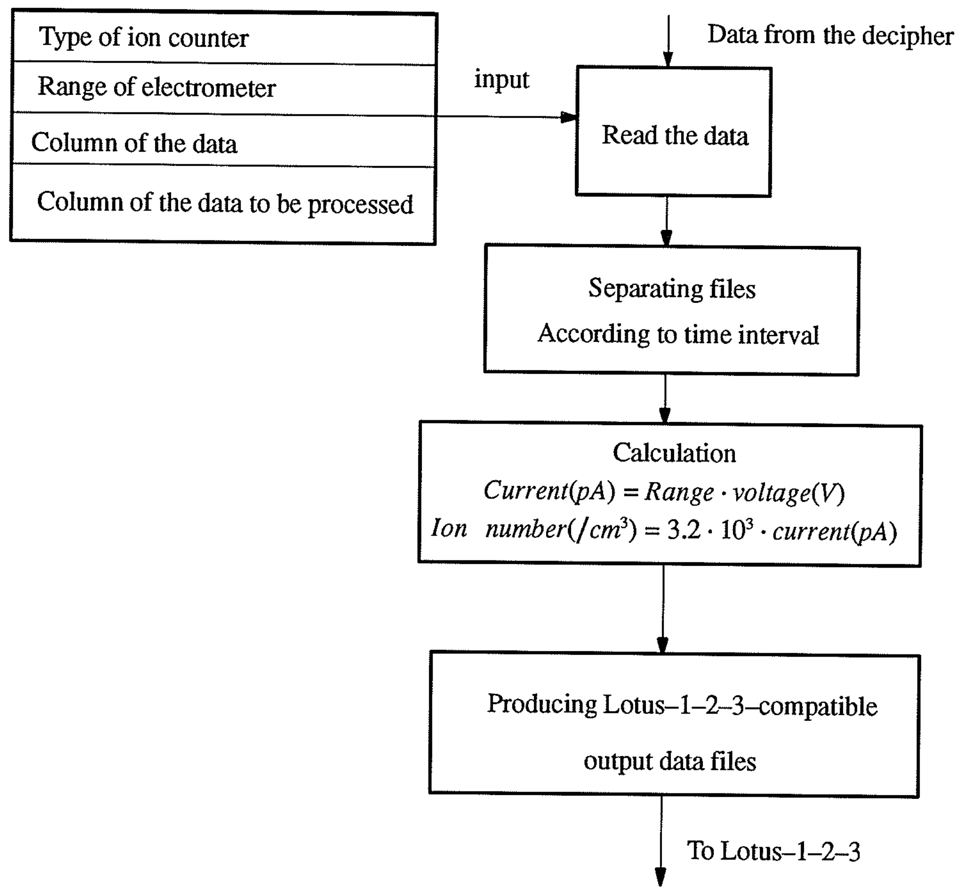


Fig. 2.9 Functions of the Utility Program

A utility program was developed to perform the above tasks automatically. The function of the utility program is shown in Fig. 2.9.

CHAPTER 3
STUDY OF AIR ION DISTRIBUTION IN AN INDOOR ENVIRONMENT

3.1 Background Room Ion Distribution

Before the experiment was carried out, the background ion densities for small, intermediate and large ions (number of ions without the presence of an ionizer) were measured. The results are shown in Fig. 3.1 to Fig. 3.3. Room temperature remained at $21^{0}C$ during the measurement, relative humidity at 38% and atmospheric pressure at 745 mmHg.

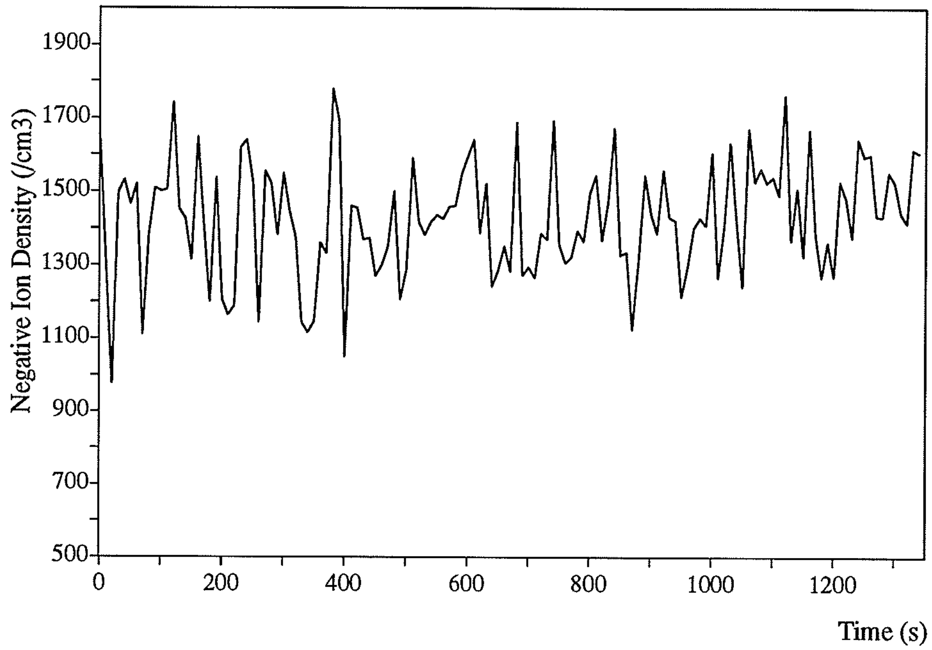


Fig. 3.1 Small Negative Ion Density

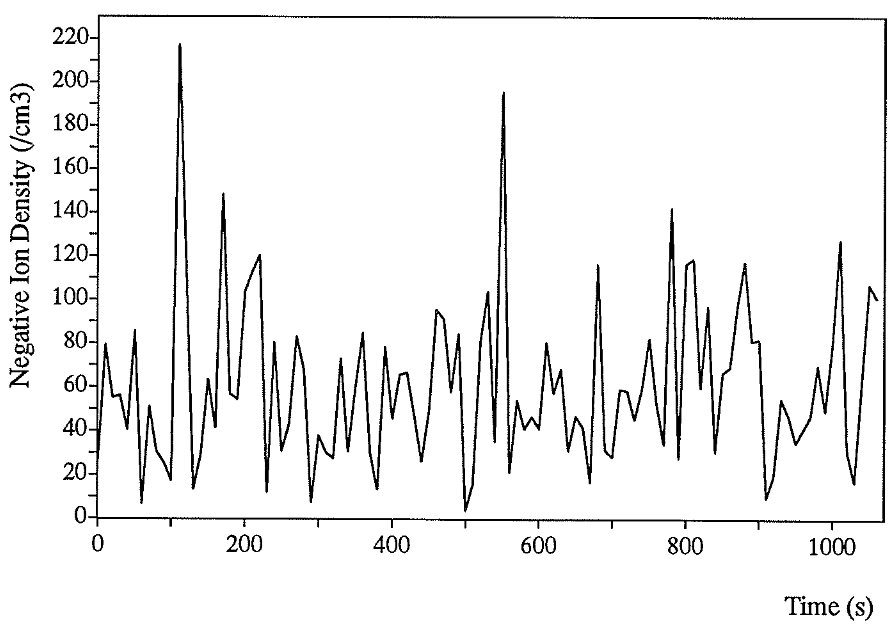


Fig. 3.2 Intermediate Negative Ion Density

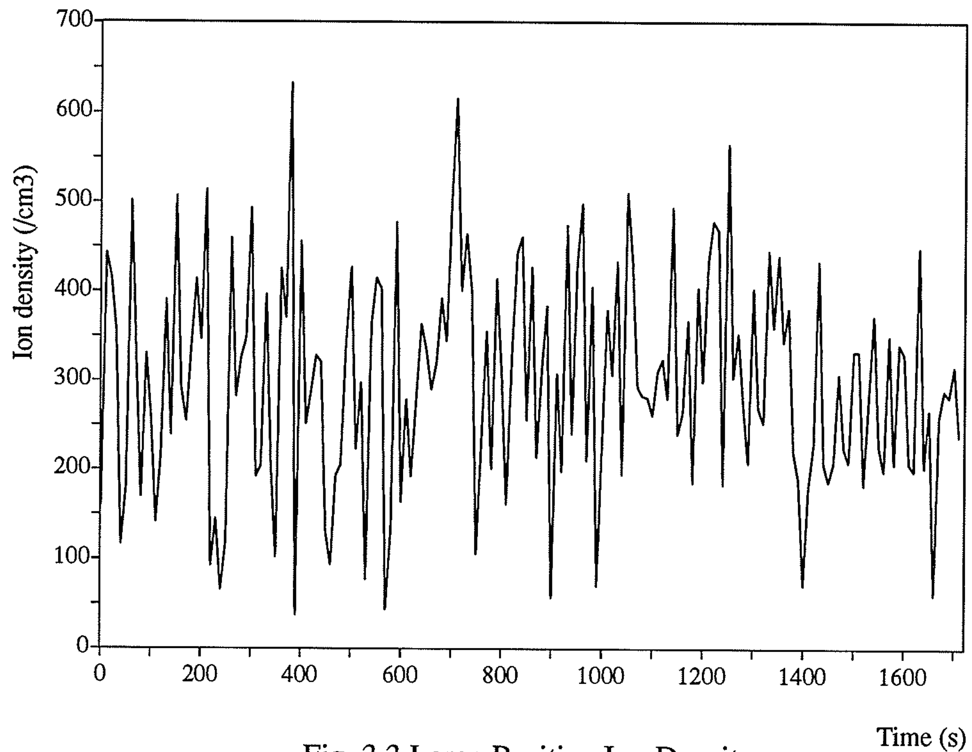


Fig. 3.3 Large Positive Ion Density

In practice, the ion density at a point is not a constant. It fluctuates with time as show in above figures. Therefore mean ion density ($\bar{n}$) is used instead:

$$\bar{n} = \frac{1}{N}\sum_{i=0}^{N} n_i \tag{4}$$

Where n_i is a sample (ion density) taken at time T_i; N is the number of samples. N is usually several hundreds.

The standard deviation, S, is a measurement of the discreteness of a sampling distribution. It is defined as follows:

$$S = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(n_i - \bar{n})^2} \tag{5}$$

Relative standard deviation, S_r, is defined as:

$$S_r = \frac{S}{\overline{n}} \cdot 100\% \tag{6}$$

In this thesis, whenever ion density is mentioned it refers to mean ion density.

With above definitions the ion density and the relative standard deviation of small negative ions, intermediate negative ions and large positive ions are calculated as shown in Table 1.

Table 1 Average Background Ion Density and Relative Standard Deviation

	Mean Ion Density (N) (/cm^3) and Relative Standard Deviation (STD) (%) N ± STD
Small negative ion	–1426 ± 10.9
Intermediate negative ion	–59 ± 68.6
Large positive ion	299 ± 41.4

The above figures and the table show that the ion densities for the three types of ions had different distribution in an indoor environment. The concentration of small negative ions was the largest.

3.2 Measurements Conducted in a Shielded Room

The experiments were conducted in a room completely shielded with single metal plates. The shielding structure is solidly connected to the high voltage laboratory ground. A carbon fibre emitter was used in the experiments. The horizontal distance between the ion counter and the emitter was 760 mm. The heights of emitter were chosen as 10, 45, 81, 115, 147, 181 and 217cm. The height of the ceiling was 237 cm. The experimental arrangement is shown in Fig. 3.4. During the measurement the room temperature was 28^0 C, the relative humidity was 35% and the pressure was 750 mmHg. It was found that the closer the emitter to the room ceiling and the ground the lower was the ion density.

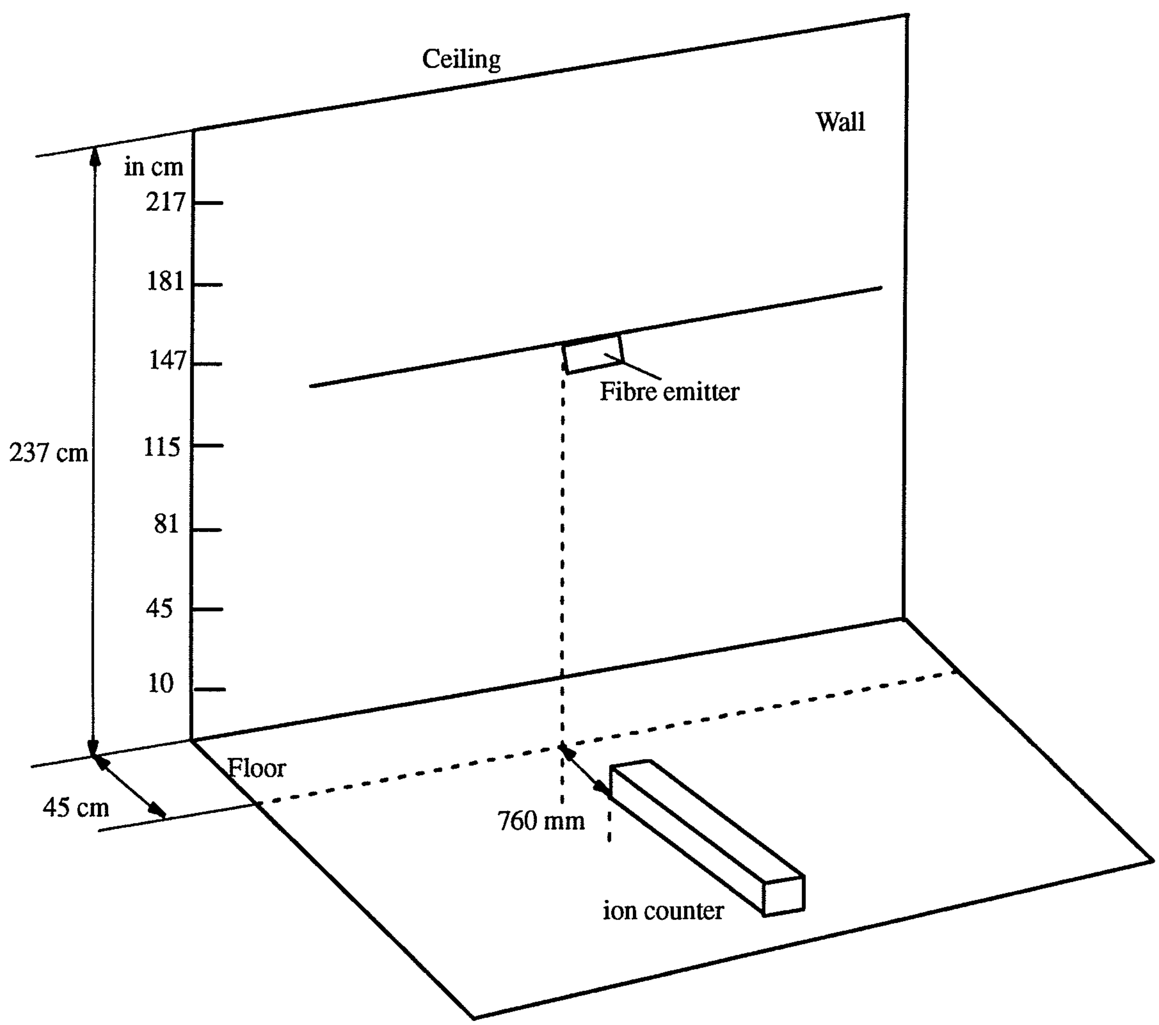


Fig. 3.4 Experimental Setup for Measuring Ion Density in a Shielded Room

Two experiments were conducted to study this case. In the first experiment the emitter and the ion counter were at the same height. The ion density was recorded when the emitter was suspended at different heights. Ion density for this case is shown in Fig. 3.5.

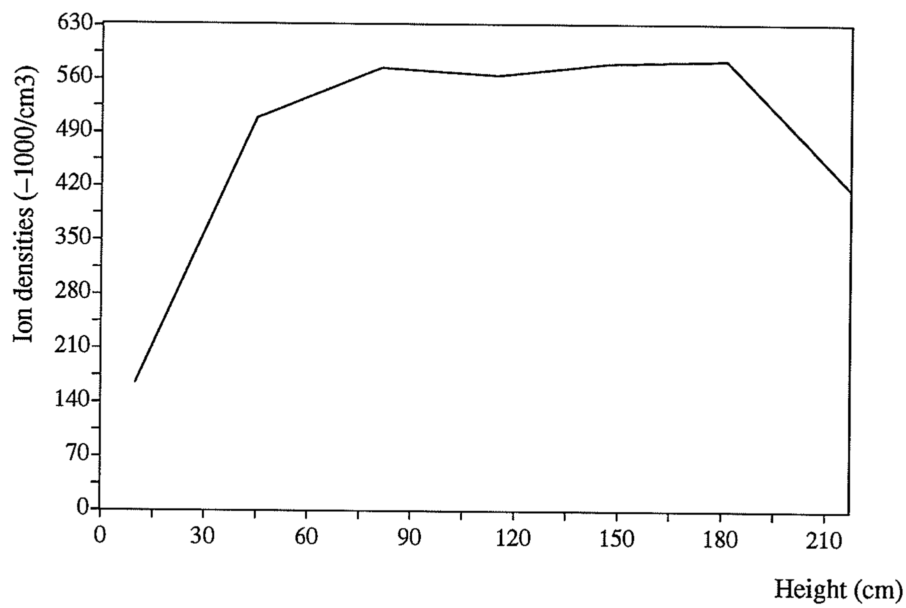


Fig. 3.5 Ion Densities as a Function of Emitter Height in Shielded Room with Emitter and Ion Counter at Equal Heights

In the second experiment the ion counter was fixed on the ground. The ion density was measured for different heights of the emitter. The ion distribution is shown in Fig. 3.6.

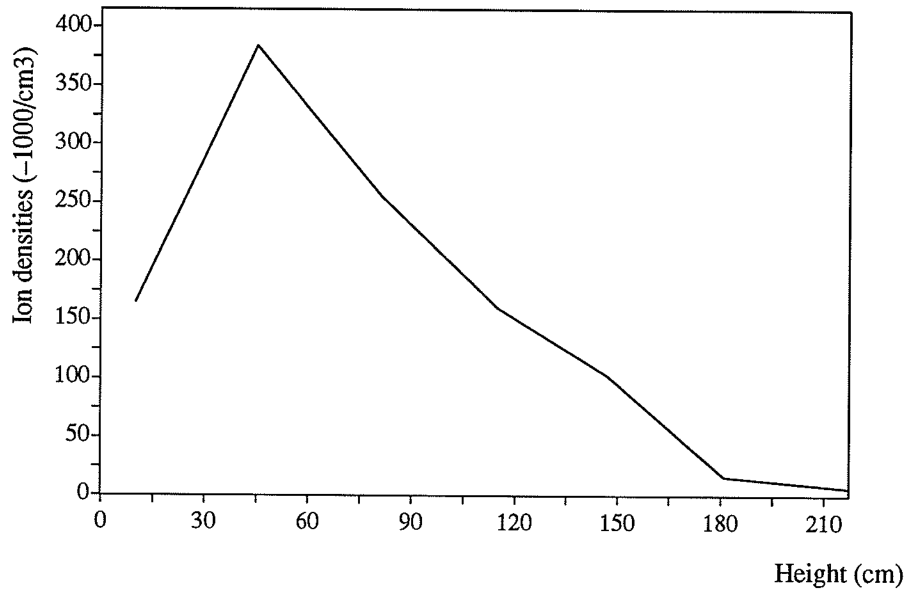


Fig.3.6 Ion Densities in Shielded Room with the Ion Counter Placed on Floor

From Fig. 3.5 it is noted that the ion densities near the ceiling and near the ground were much lower than that at other heights for the same relative position of the ion counter and the emitters. Fig. 3.6 indicates that the ion density near the ceiling decreased to zero when the ion counter was on the floor. The above two figures show that the closer the emitter to the ceiling or to the ground the lower the ion density. The results suggest that ions are attracted and removed by the grounded metal.

3.3 Grating Effects

For ion generators installed in restaurants it would be desirable to place the emitters behind a plastic or metallic grating to make the emitters less visible to the public. The question arises whether the plastic or metallic gratings would affect the ion concentration. To study this effect an experimental setup was used as shown in Fig. 3.7.

In the study a carbon fibre emitter was used and three types of gratings were employed: plastic, floating metallic and grounded metallic. The gratings used were 31 cm in width and 59.7 cm in length with a mesh size of 15.2 by 15.2 mm. The grating was suspended horizontally, 10.2 cm below the emitter. The ion counter was placed on the ground directly underneath the emitter. The room temperature in this case was 22^0 C. Relative humidity was 43% and atmospheric pressure 750 mmHg. The results obtained are shown in Fig. 3.8.

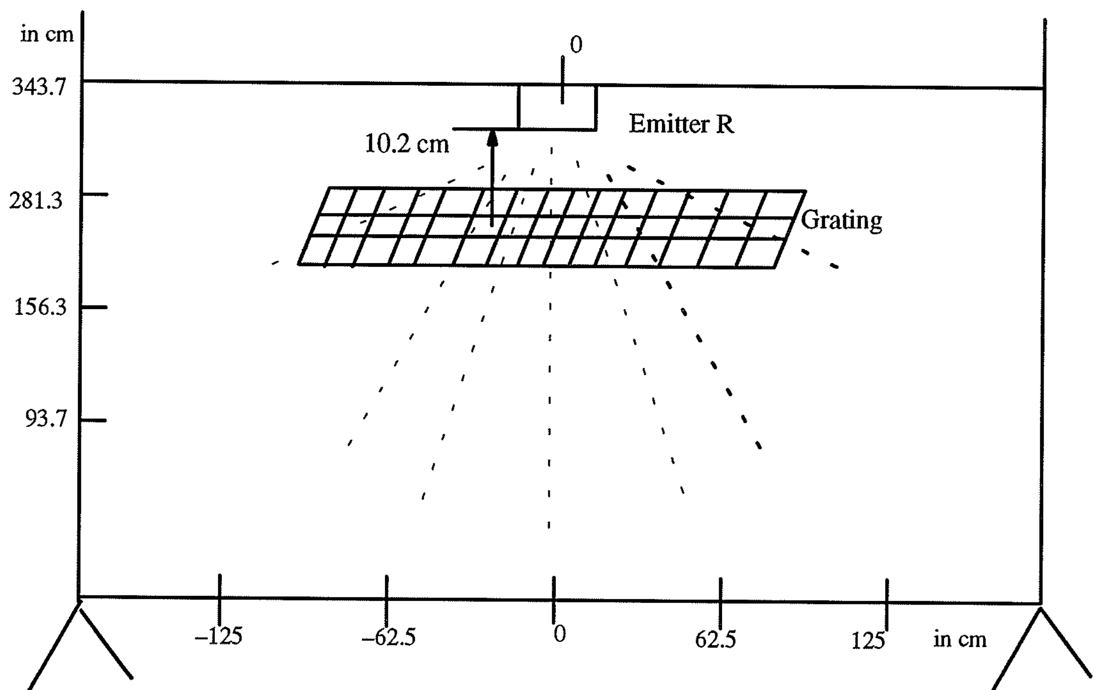


Fig. 3.7 Effect of the Grating

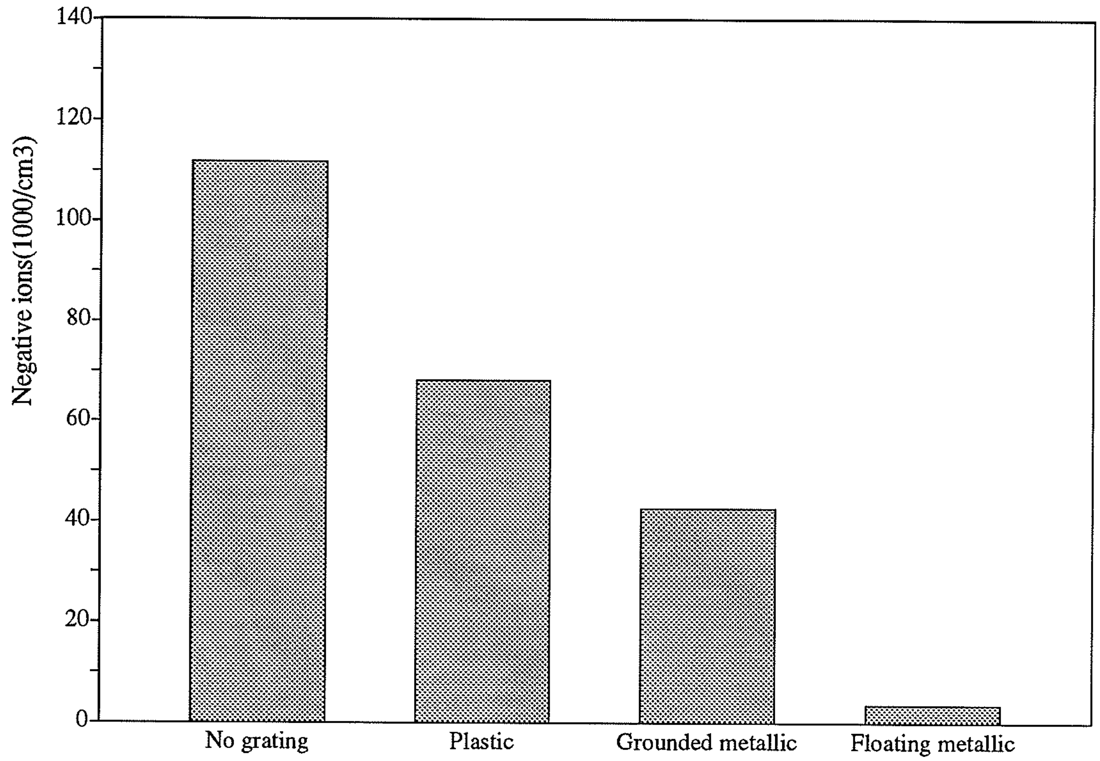


Fig. 3.8 Effect of Grating

Without any gratings the negative ion concentration reached 111.8 (thousand/cm^3). When gratings were used the ion concentration decreased significantly. The ion density with a plastic grating was the highest.

Six–hour experiment was conducted to evaluate the stability of ion concentration in the presence of a plastic grating. The ion distribution is shown in Fig. 3.9. The relative standard deviation for this case was 13%.

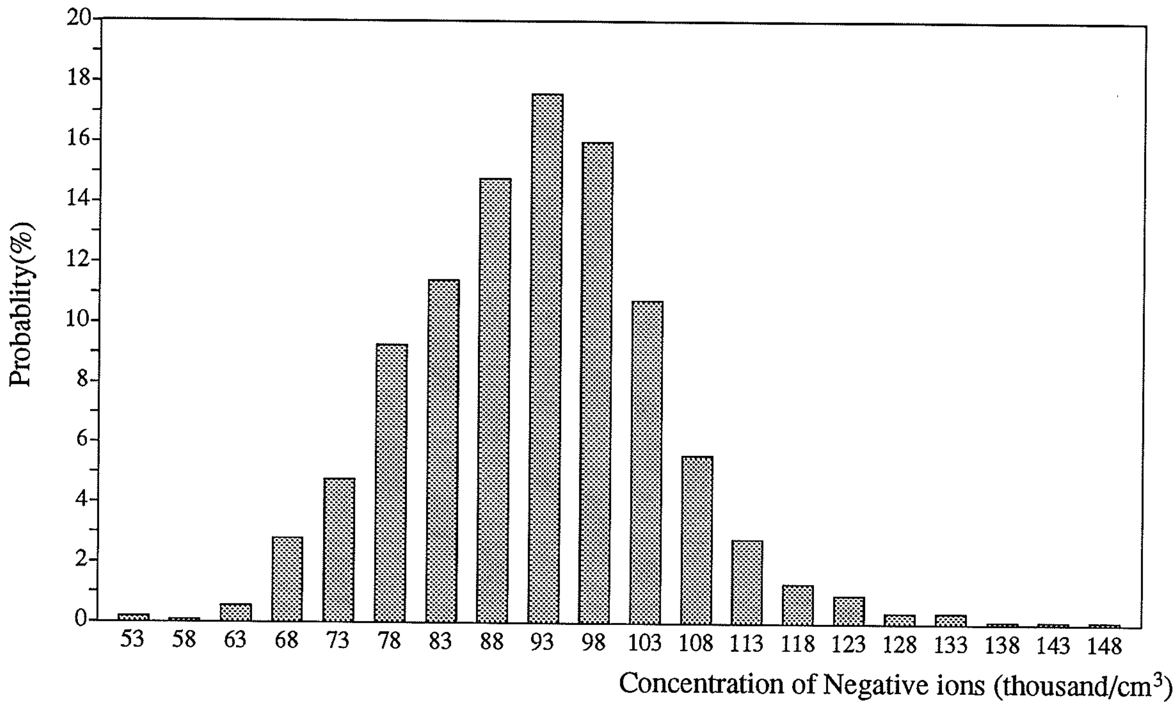


Fig.3.9 Ion Probability Distribution in the Presence of a Plastic Grating

Normally the emitters are suspended below a grounded metallic ceiling. Hence, experiments were conducted using different gratings suspended horizontally 10.2 cm above the emitter. The experimental arrangement and grating sizes were the same as the ones in Fig. 3.7, except that gratings were above the emitter. The data are shown in Table 2 .

Table 2 Grating Effects

Grating	Ion Densities (N) (–1000/cm³) and Relative Standard Deviation (STD) (%) N ± STD
None	28 ± 31
Metallic	22 ± 51
Grounded metallic	22 ± 32
*Grounded metallic plus plastic	33 ± 17

* The plastic gratings was suspended 5.1 cm above the emitter and the grounded metallic grating was 5.1 cm above the plastic grating.

These data show that if an emitter is suspended directly under the ceiling, the ion distribution would decrease. Inserting a plastic grating between the ceiling and the emitter increases ion concentration.

3.4 Wall Effects

To investigate the effect of the wall, an experimental arrangement was setup as shown in Fig. 3.10. In the first experiment 6 emitters were connected in series. The emitters were placed at 75 cm above ground and 270 cm from the wall. Distance between the emitters was 15 cm. The ion counter was placed in front of the center of the emitters and at the same height. The horizontal distance between the ion counter and the emitters was 50 cm. Room temperature was 22^0 C and the relative humidity 54%. The measured data are shown in Fig. 3.11. In the second experiment 10 emitters connected in series were fixed on the wall. Other arrangements remained the same as in the first experiment. The measured ion density in this case is presented in Fig. 3.12.

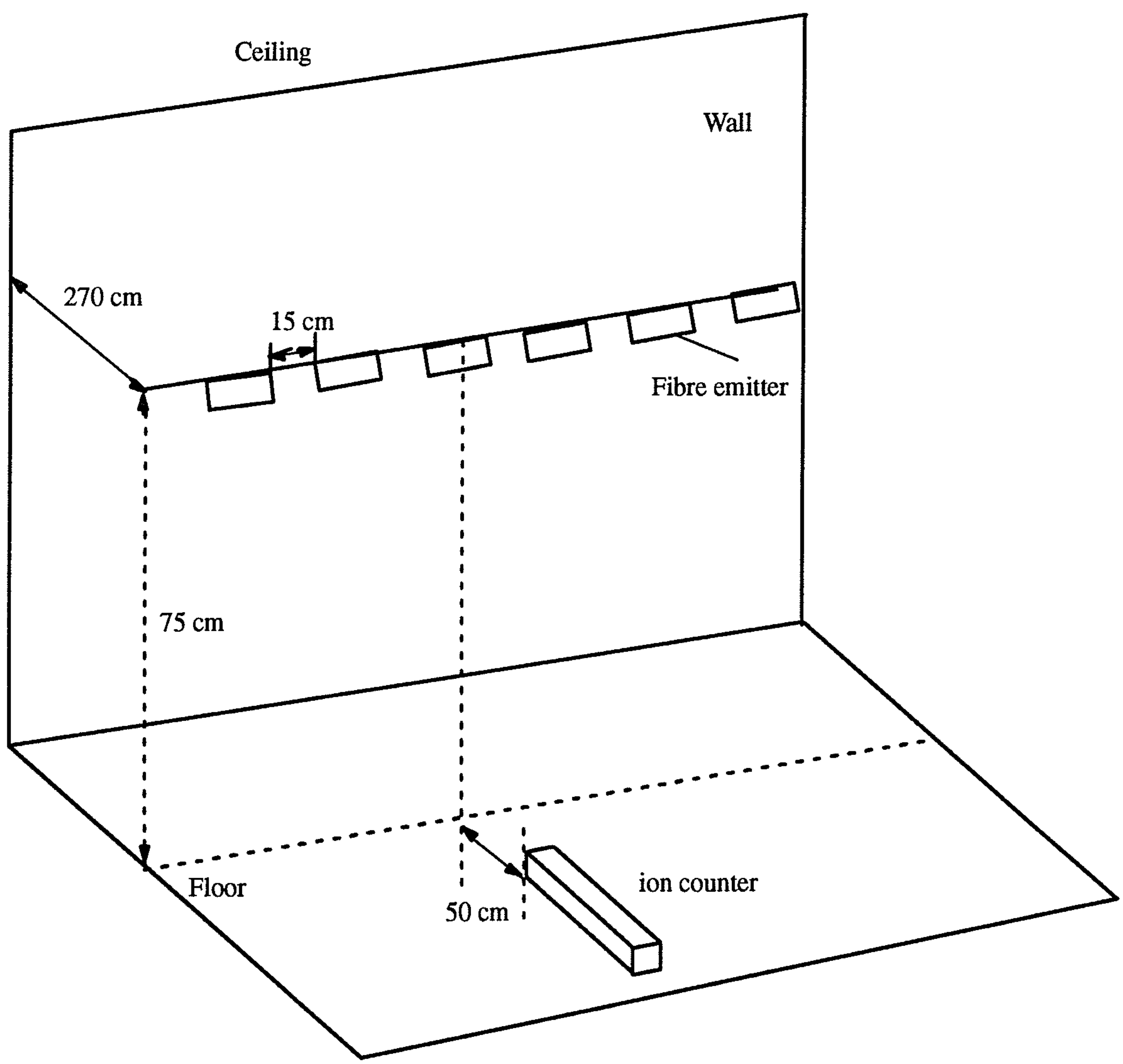


Fig. 3.10 Experimental Setup for Measuring Ion Density with Multiple Emitters Far From the Wall

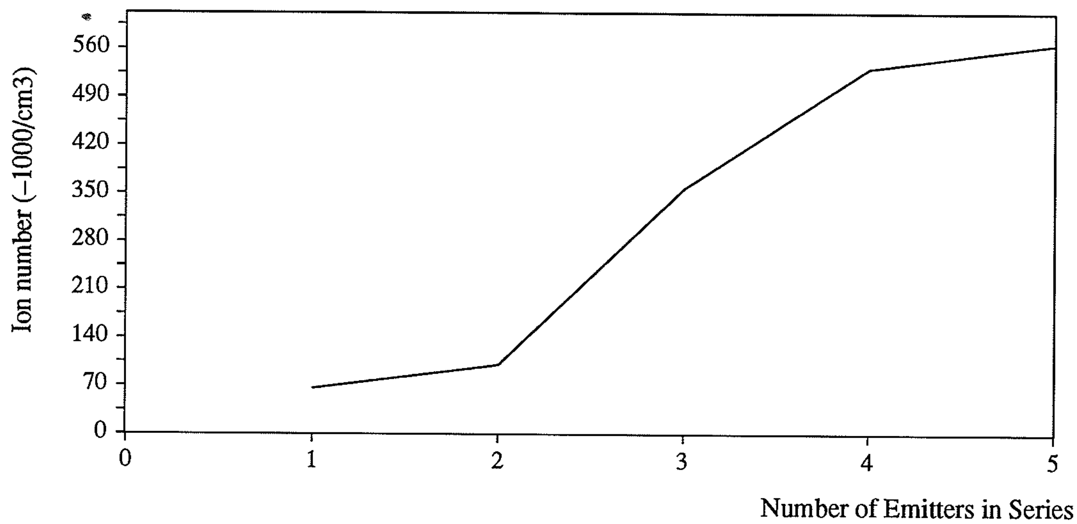


Fig. 3.11 Ion Density for Multiple Emitters Far From the Wall

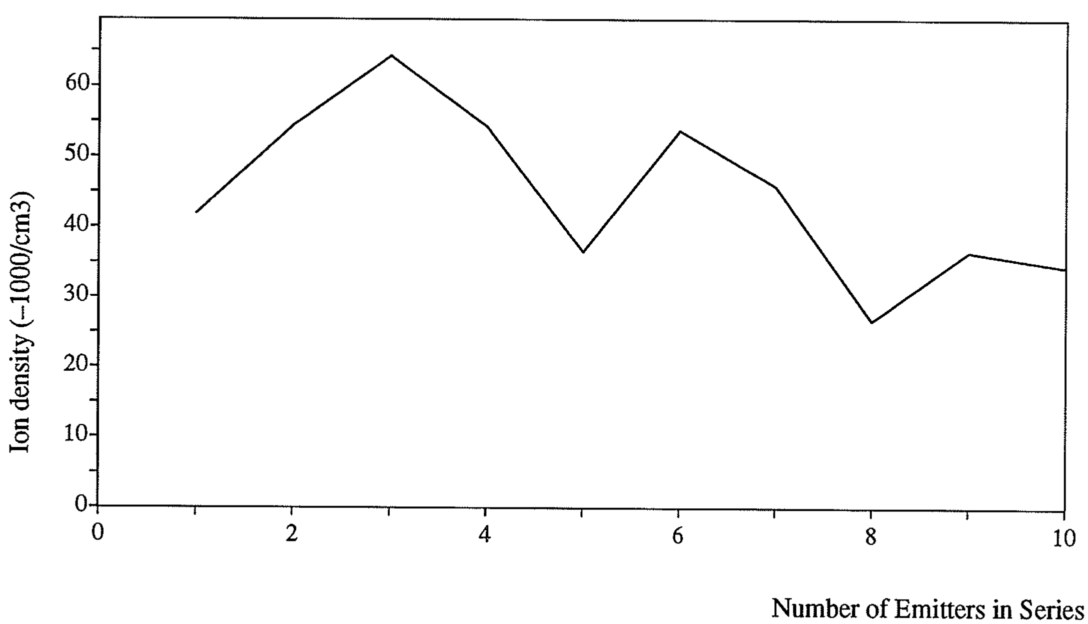


Fig. 3.12 Ion Density for Multiple Emitters on the Wall

Fig. 3.11 indicates that the ion density with the emitters placed far from the wall increased with the number of the emitters connected in series. In this case the ion density seems to reach a maximum when the number of emitters exceeds four connected in series. Fig. 3.12 shows that the ion density of the emitters fixed at the wall fluctuates with the increase of the number of the emitters in series. The emissivity of the emitters on the wall was not monotonic. In general the ion density measured on the ground produced by the emitters located far from the wall is approximately ten times higher than that for the emitters on the wall.

3.5 Ventilation System

Usually there is a ventilation system in an office. To study the effects of a ventilation system on an ion–generating system a carbon fibre emitter was chosen. The emitter was suspended 84 cm above ground. The ion counter was placed on the ground directly underneath the emitter. To get the profile of ion distribution the ion counter measured the ion density at horizontal ground level "–62.5", "–31.25", "0", "62.5" and "31.25" in cm from left to right in the room. Experimental arrangement is shown Fig. 4.15 in Chapter 4. In the laboratory there were three air ducts located in the right of the experimental site. The distance between the duct and experimental site was 241.3 cm. The room temperature was 17^0 C to 20^0 C, the relative humidity was 53% and atmospheric pressure was 741 mmHg. The ion densities and relative standard deviation with and without ventilation are shown in Table 3.

Table 3 Effect of Ventilation

Horizontal position in cm	Average ion density (N) (–1000/cm^3) and Standard Deviation (STD) (%)	
	Without ventilation N ± STD	With ventilation N ± STD
–62.5	381 ± 1.5	280 ± 3.4
–31.25	584 ± 1.1	538 ± 6.6
0	649 ± 1.4	610 ± 5.2
31.25	503 ± 1.2	502 ± 7.1
62.5	260 ± 2.7	285 ± 5.9

The table shows that the ion density with the ventilation system on or off does not have large difference. However the relative standard deviation without ventilation is much lower than that with ventilation. Therefore the ventilation system does not affect the ion distribution but does influence the variability.

3.6 Fan Effect

In some ion–generating systems the ionizers are installed in a duct from which strong air currents emerge. To study this phenomenon a fan was suspended above a carbon fibre emitter. Using the same experimental arrangement as described in Section 3.5 the ion distribution and the relative standard deviation were recorded both with and without a fan. The results shown in Fig. 3.13 and Fig. 3.14 respectively. The room temperature was 20^0 C, the relative humidity 56% and the atmospheric pressure 751 mmHg.

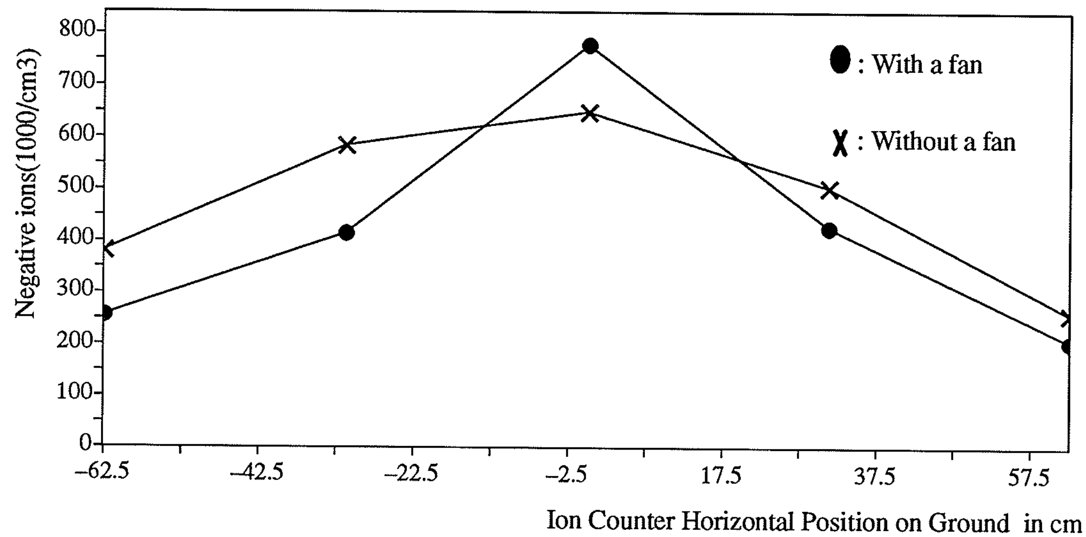


Fig. 3.13 Average Negative Ion Density with and without a Fan

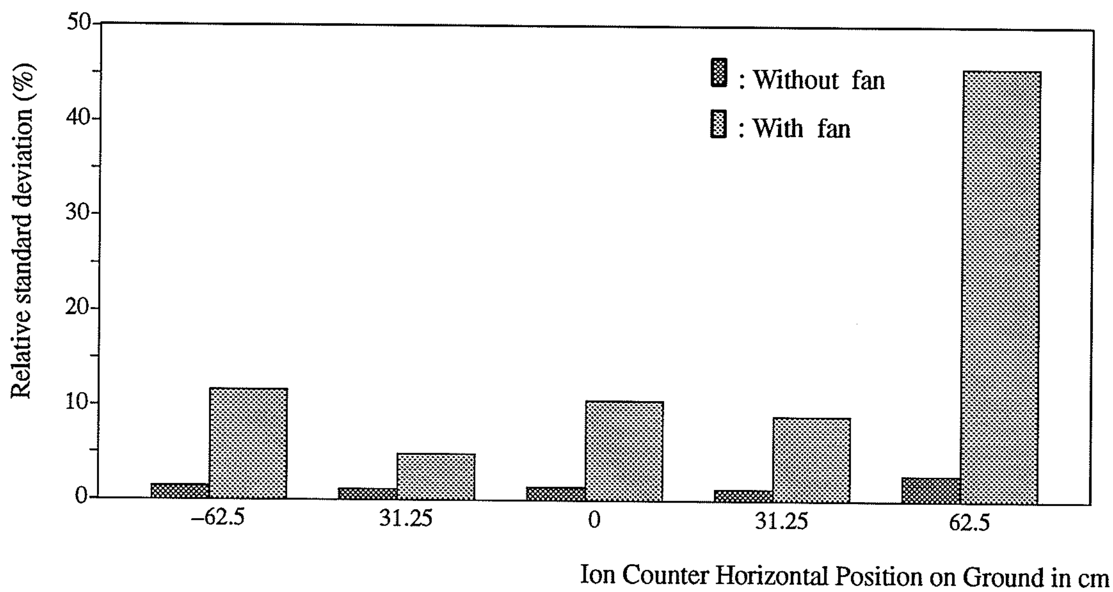


Fig. 3.14 Relative Standard Deviation With and Without a Fan

The figures demonstrate that the ion density with a fan is higher than that without a fan only at the center of the emitter. The curve giving the average ion density and the relative standard deviation for the condition without using a fan is flatter than that with a fan.

This indicates that the stable and constant range of ion density without a fan is much wider than that with a fan.

3.7 Ion Distribution in Space Surrounding a Single Emitter in an indoor Room

To study the ion distribution in a controlled room with an ion generating system the following experiment was conducted. In the indoor room, temperature, humidity and atmospheric pressure were monitored. A carbon fibre emitter was suspended, above the ground at the following heights 93.75, 156.25, 218.75 and 281.25 cm respectively. The experimental setup is shown in Fig. 4.2. The ion counter was placed on the ground directly underneath the emitter. During the experiment the laboratory temperature was approximately 22^0 C, the relative humidity was 34% and the atmospheric pressure 755 mmHg. The measured ion density distribution at various positions are shown in Fig. 3.15.

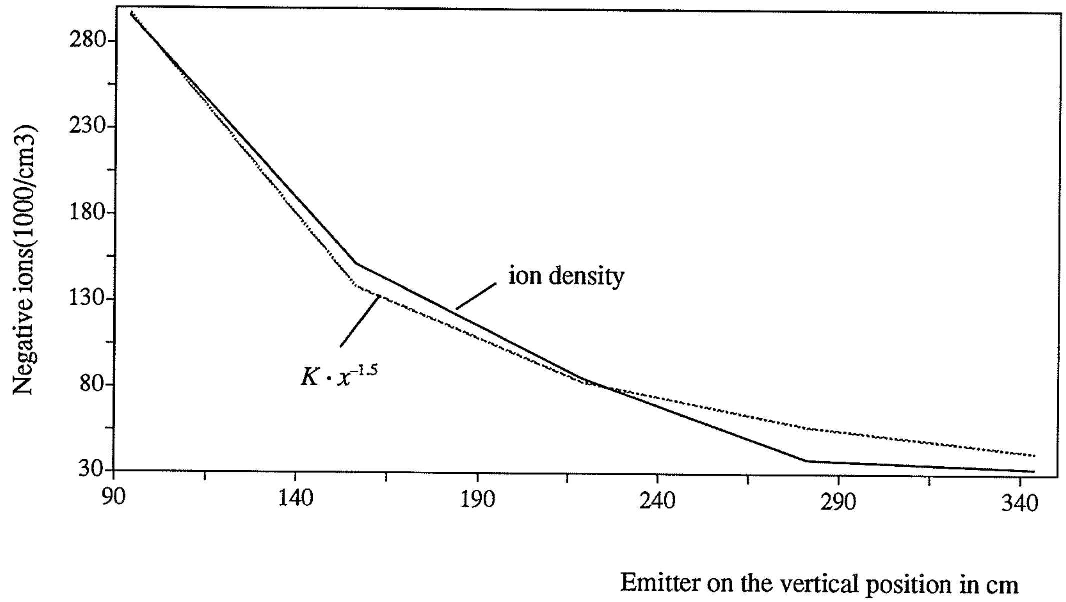


Fig. 3.15 Ion Distribution Produced by a Carbon Fibre Emitter

The figure shows that the ion density decreases approximately exponentially with increasing the height of the emitter location.

The ion distribution shown in Fig. 3.15 follows closely an exponential function $K \cdot x^{-1.5}$, where K is a constant and x is the height of the emitter above ground. The experimental and the calculated curves are very close.

CHAPTER 4
EVALUATION OF THE ION GENERATING SYSTEM

4.1 DC Voltage Source

Variations in the magnitude of the 60 Hz AC voltage will cause fluctuation in the DC output voltage which in turn will affect the performance of the system. As a test step it was decided to investigate the relationship between the DC voltage and the resulting ion density.

For this purpose a carbon fibre emitter was suspended at 155 cm above ground and the ion concentration was measured every 10 seconds while varying the DC voltage from 4.6 kV to 8.3 kV. The data obtained are shown in Fig. 4.1.

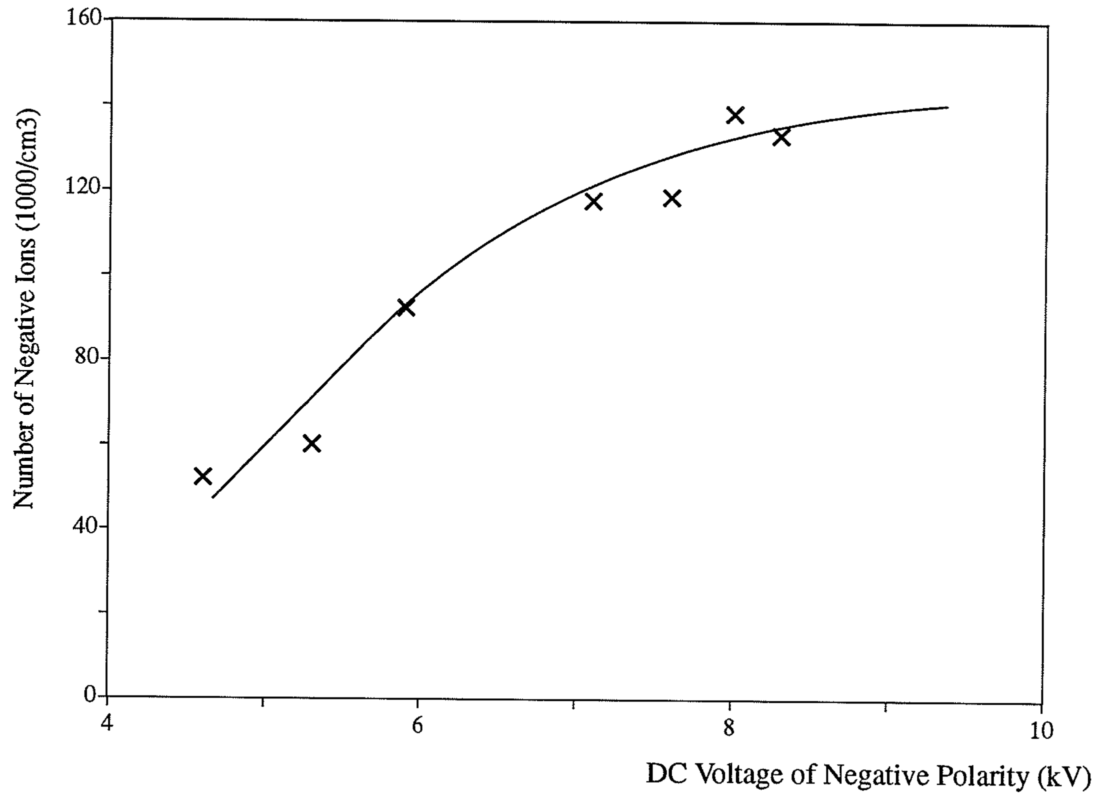


Fig. 4.1 Ion Concentration vs. DC Voltage

Fig. 4.1 shows that the concentration of ions tend to saturate as the voltage increases. When the DC voltage exceeds 8 kV the ion emission does not increase significantly as the voltage is increased.

In practical applications the ion–generating system consists of many emitters connected in series. It was of interest to investigate whether the output voltage of the source does not drop significantly as the number of emitters is increased. In this test the DC high–voltage source was connected to one emitter and the output voltage of the unit was measured, the same procedure was then followed in two further tests, using three emitters and five emitters connected in series respectively. The DC voltage of the generator was measured with an electrostatic voltmeter. The measurements were repeated for emitters at different heights. It was observed and recorded that the output voltage from the DC high voltage source remained constant at 7.25 kV from zero up to five emitters connected in series. This shows that, over the range tested, the voltage was independent of both the number of emitters connected in series and the height of emitters. If a large number of emitters were connected in series, however, the voltage would likely decrease due to a significant increase of load current. The current from the unit during the experiment was smaller than 1 μA, too small to be measured due to the inadequate equipment sensitivity.

The DC voltage decreased considerably when the emitters were placed close to a grounded object as shown in Table 4. The last row in the table was obtained with an emitter placed 4 inches above a grounded metallic grating.

Table 4 DC Voltage Changes with Multiple Grating

Gratings	DC Voltage (kV) from a unit
Without Grating	7.69
Plastic Grating	7.65
Floating Metallic Grating	7.65
Grounded Metallic Grating	6.95

4.2 Fibre Emitters

During the experiments the ion distribution for multiple carbon fibre emitters at various positions were recorded to understand the relationship between the efficiency of the emitters and the location of the emitters.

Two ion counters were used for comparison purpose, one (Beckett type) from the high voltage laboratory of the University of Manitoba (UM) and the other (134B type) from Neg–Ions (North America) Inc. During the comparison, the Beckett and 134B were used to measure both small and intermediate ions. Various measurements have indicated that the data observed with both ion counters agreed fairly closely as shown in Table 5.

Table 5 Comparison of the Two Ion Counters

Type of ion counter		Ion Numbers (N) (–1000/cm^3) and Relative Standard Deviation (STD) (%) $N \pm STD$	Environment conditions
134B (Neg–ions Inc.)		151 ± 27.3	RH: 50%
Beckett (UM)	Small ions	100 ± 23.6	T: 27^0C
	Intermediate ions	22 ± 42.7	P: 757 mmHg

To determine the ion emissivity of the emitters, a wooden frame structure was constructed on which the emitters were suspended. The structure was designed to simulate the practical conditions. The wooden frame structure is shown in Fig.4.2. For easy reference, a rectangular coordinate system was set for the wooden frame. The origin of the coordinate is located on the ground at the center. The horizontal and vertical coordinates are represented by *x* and *y* respectively. The *x*–coordinate is positive to the right of the center. Therefore, coordinate (10cm, 20cm) represents the position 10cm to the right of the center and 20cm above the ground.

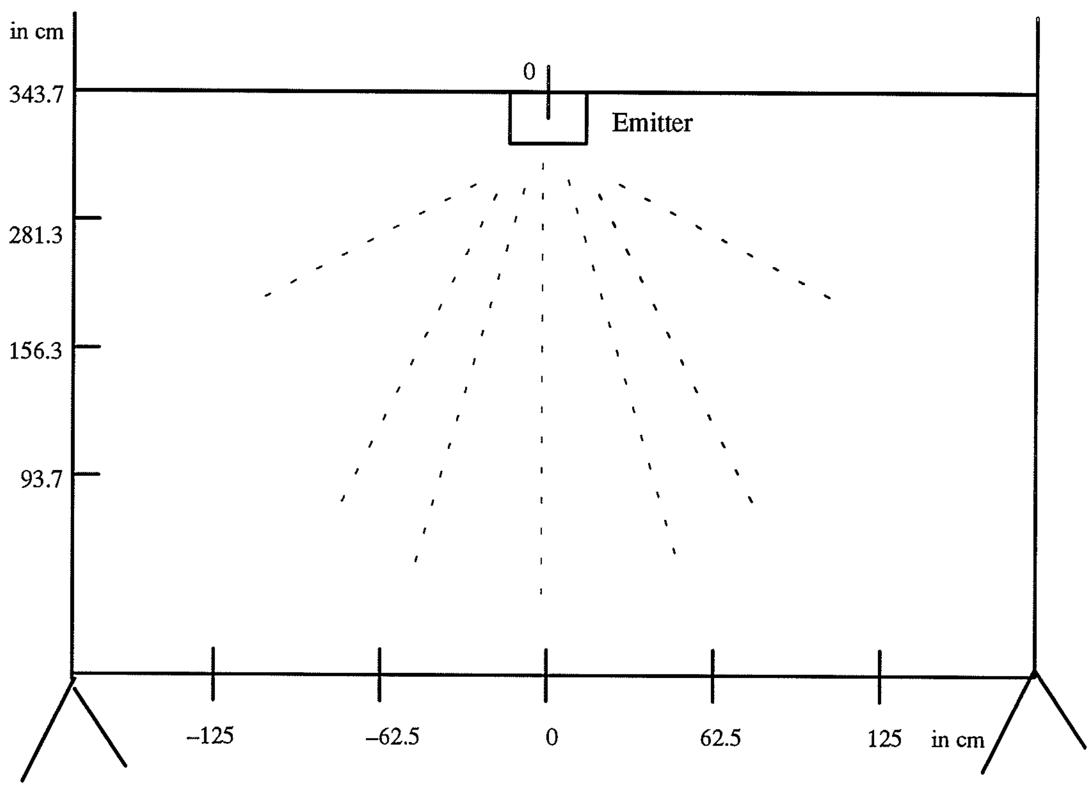


Fig. 4.2 Wooden Frame Structure

To determine the ion emission characteristics of the emitters of different configurations, seven types conducting fiber emitters of different configurations, shown in Fig. 4.3, were tested.

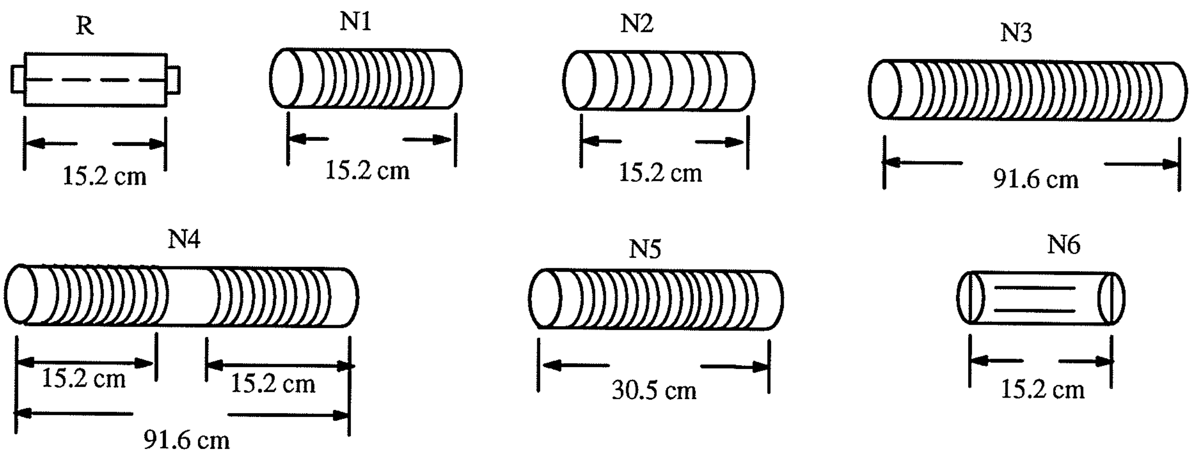


Fig. 4.3 Seven Types Emitters of Different Designs

4.21 R Type Emitter

The rectangular emitter R was studied to determine the effects of the position of emitter. Emitter R has 4 sections of carbon fibers protruding from the casing. It was extensively used as controlled test emitter in Neg–Ions (United Kingdom) Inc. During the measurements the laboratory temperature was approximately 22^0 C. The relative humidity was 34%. Atmospheric pressure was 755 mmHg. Under these environmental conditions the measured ion density distribution was found to vary as shown in Fig. 4.4.

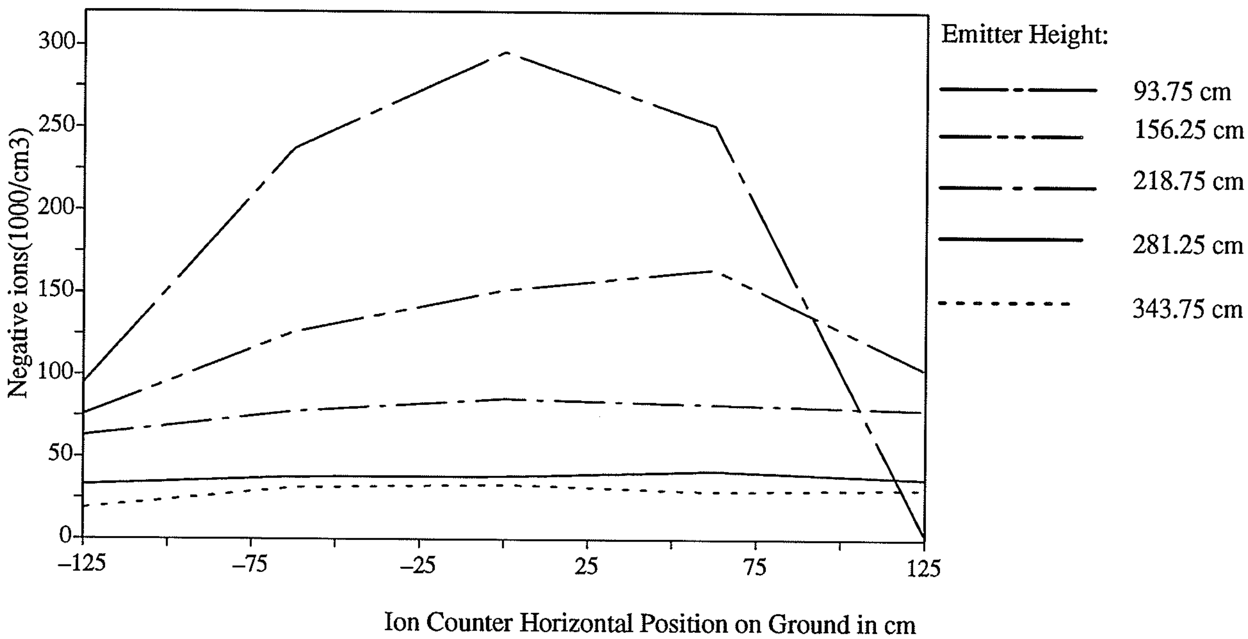


Fig. 4.4 Ion Distribution for Rectangular (R) Emitter

Fig. 4.4 shows that with increasing emitter height the ion concentration at ground level decreased and the ion distribution became more uniform. The sudden decrease of ion concentration observed in position 125, height 93.75 cm may be explained by the proximity of an air duct and the wall.

4.22 Evaluation of Emission Effectiveness for Different Types of Emitters – N1 to N6

To evaluate the effectiveness of emission of different lengths of sections of carbon fiber emitters, two types of emitters designated as N1 and N2 were studied, the results are shown in Fig. 4.5 and Fig. 4.6. The emitter N1 has 9 sections of carbon fibers while emitter N2 has 3 sections. Their lengths were equal (15.2 cm). Their configurations are shown in Fig. 4.3. During these measurements room temperature remained around 22^0 C. The relative humidity was 38%, atmospheric pressure was 749 mmHg.

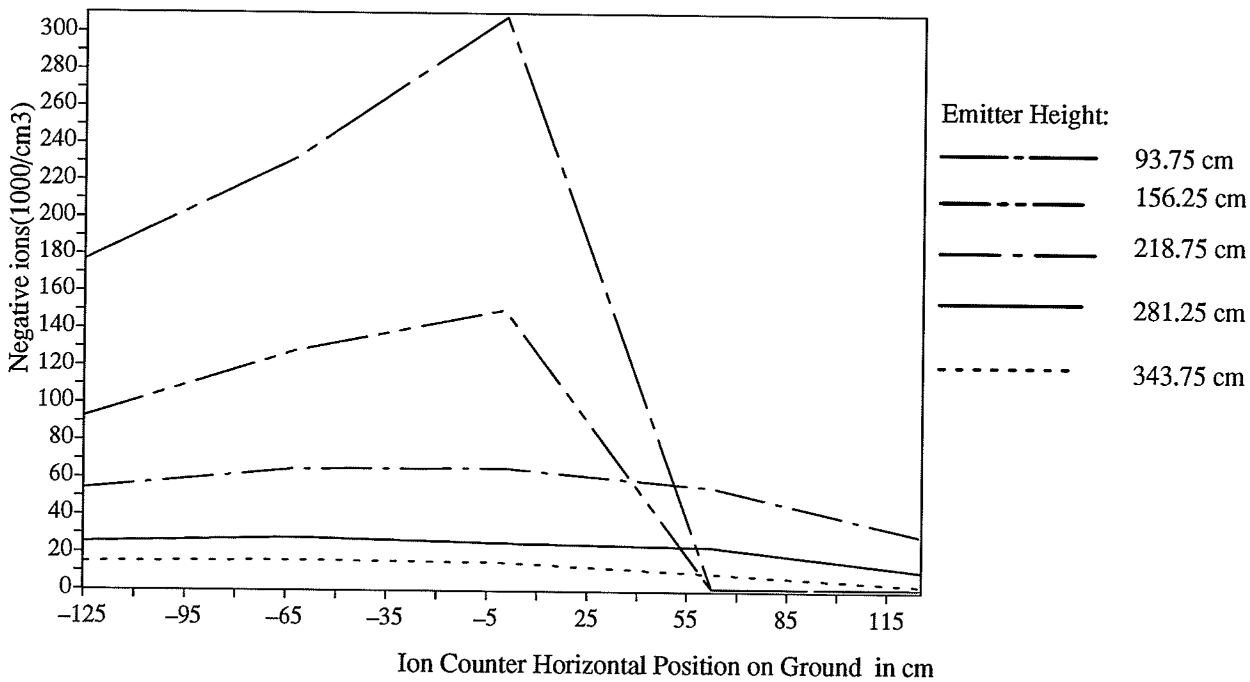


Fig. 4.5 Ion Distribution for Emitter N1

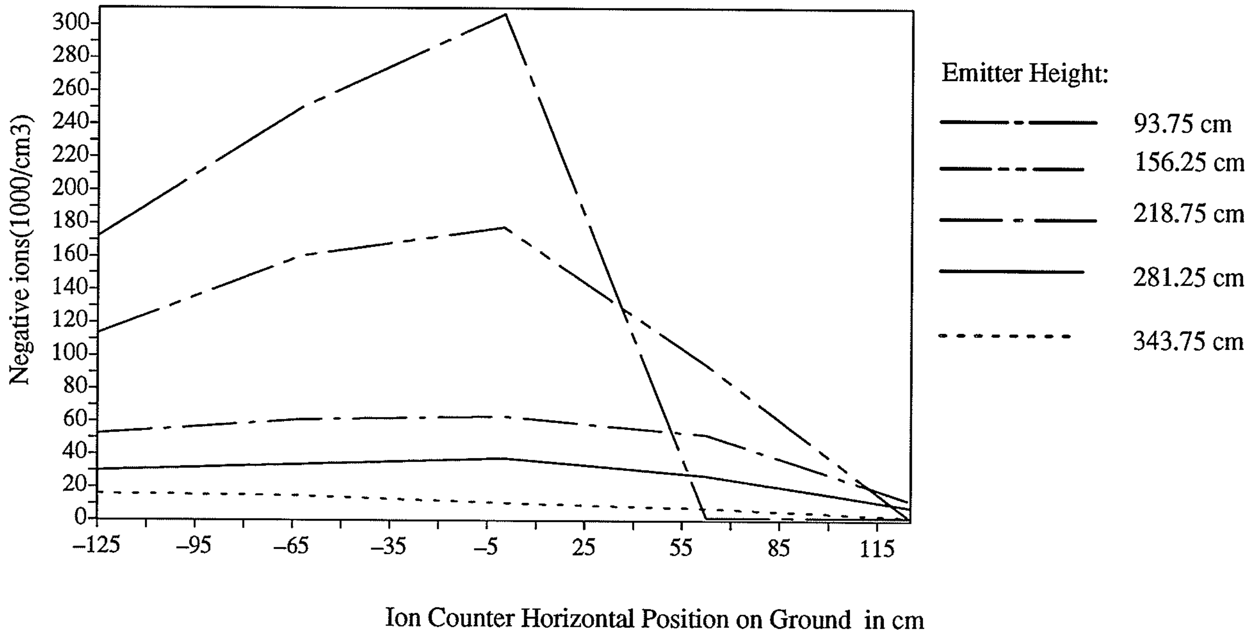


Fig. 4.6 Ion Distribution for Emitter N2

The data presented in Figs. 4.5 and 4.6 show that the ion densities produced by the two types of emitters are similar. The ion concentration decreases rapidly to the right of the emitter's position, due to the proximity of an air duct and the wall.

To check this further, emitters N3, N4, N5 and N6 were studied. Their fibre arrangements are shown in Fig. 4.3. The room temperature was 22^0 C, the relative humidity 39%. Atmospheric pressure was 745 mmHg. Their measured ion distributions are shown in Fig. 4.7–Fig. 4.10 respectively.

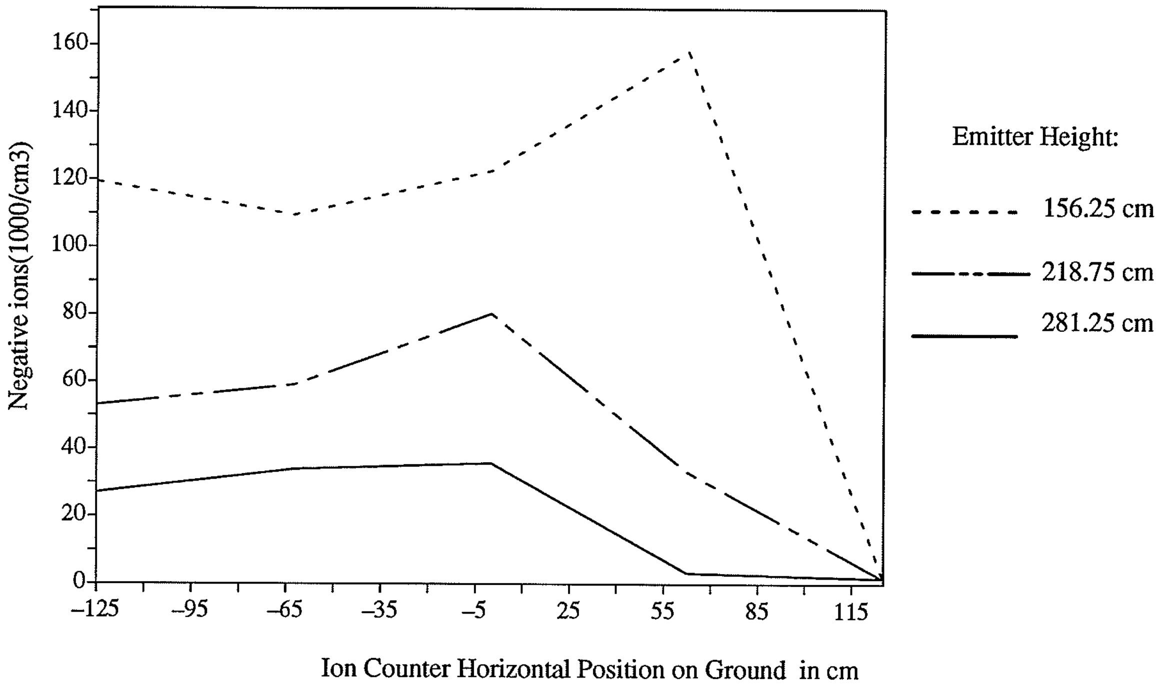


Fig. 4.7 Ion Distribution for Emitter N3

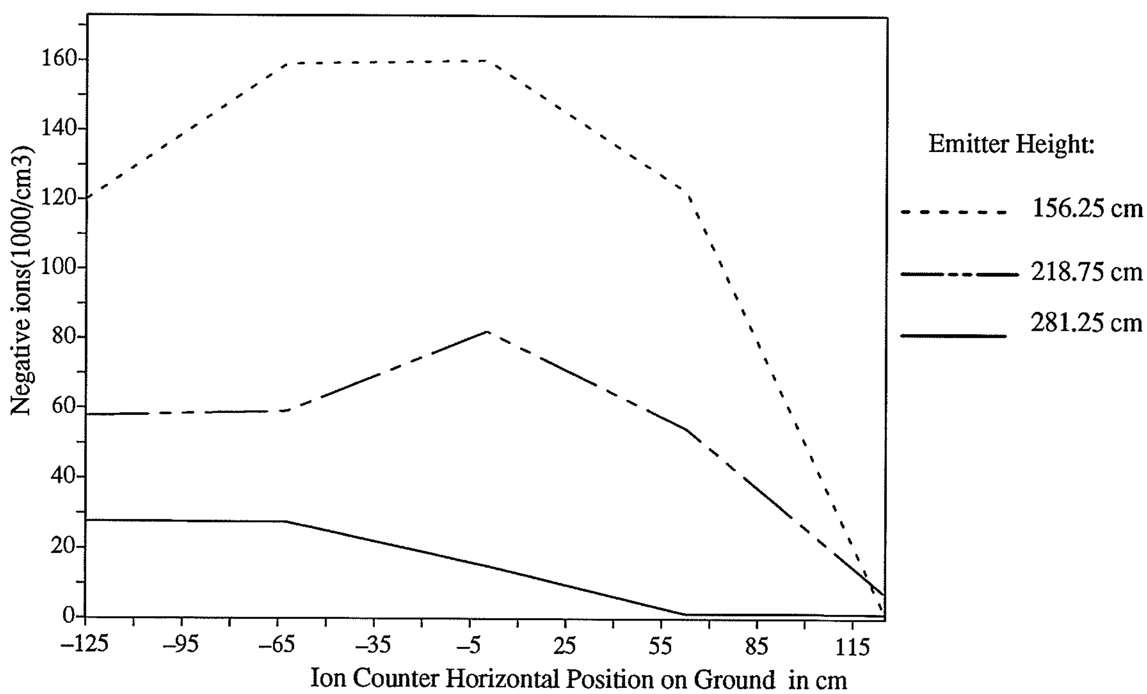


Fig. 4.8 Ion Distribution for Emitter N4

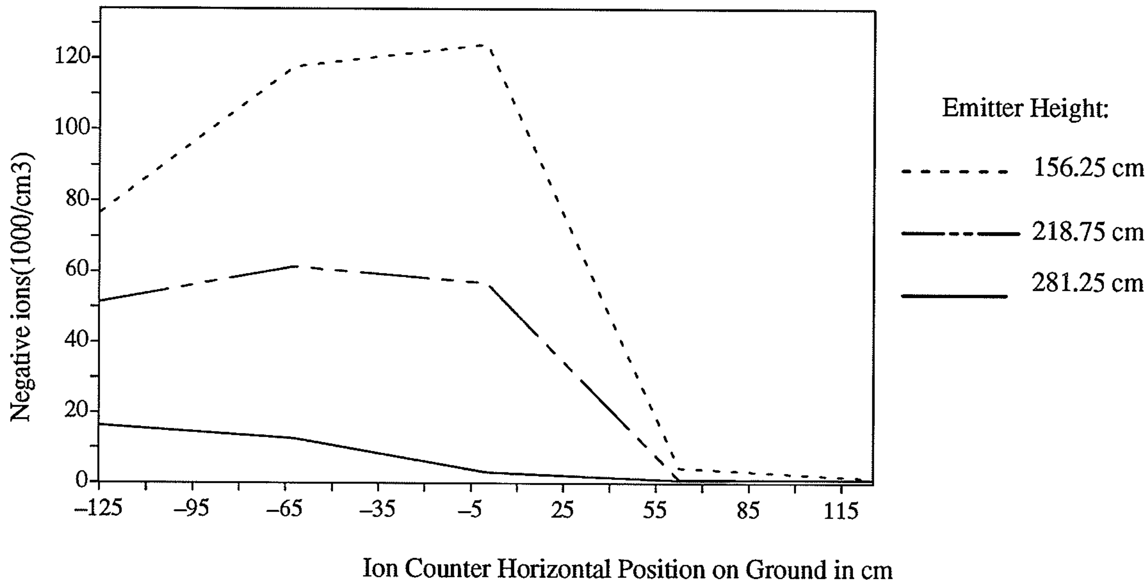


Fig. 4.9 Ion Distribution for Emitter N5

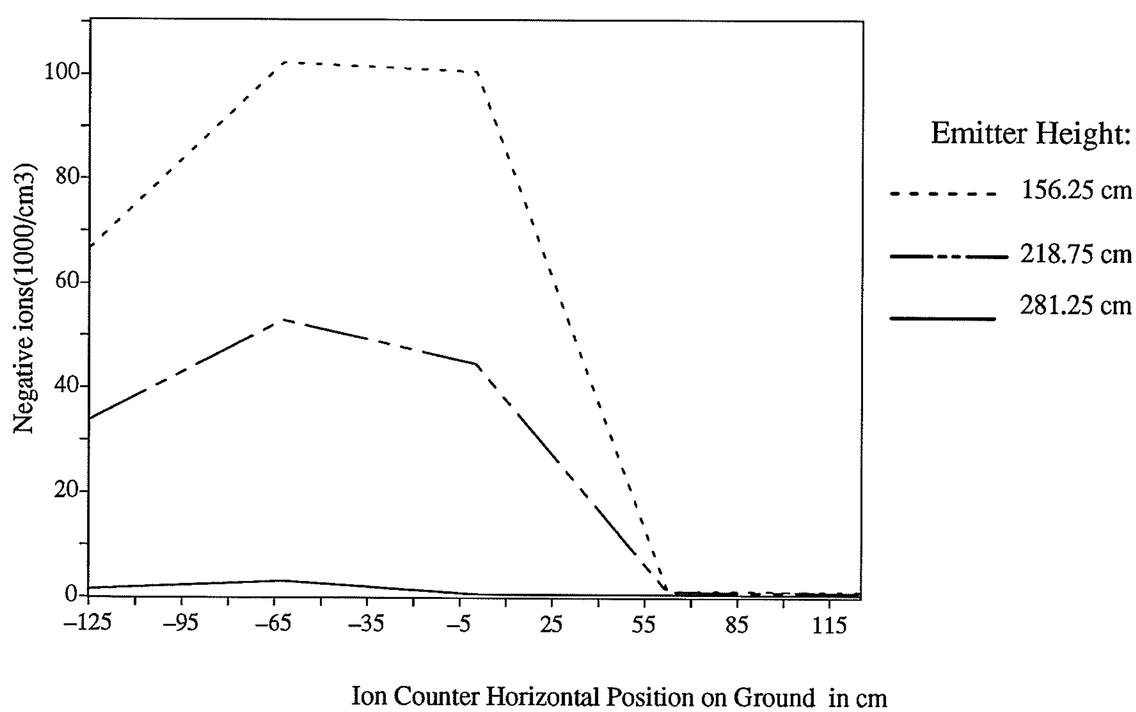


Fig. 4.10 Ion Distribution for Emitter N6

Table 6 Average Ion Density for Emitter N1

Horizontal position in cm	Heights	Average ion density (–1000/cm^3)			
	93.75 cm	156.25 cm	218.75 cm	281.25 cm	343.75 cm
125	176.8	92.3	53.9	25.4	14.7
–62.5	231.8	127.9	64.5	27.8	15.8
0	308.4	150.2	65.2	25.2	14.8
62.5	1.2	1.2	55.3	23.4	9.3
125	1.3	1.1	29.5	10.7	3

Table 7 Average Ion Density for Emitter N2

Horizontal position in cm	Heights in cm	Average ion density (–1000/cm^3)			
	93.75	156.25	218.75	281.25	343.75
125	172.1	113.4	52.4	29.8	15.7
–62.5	249.6	160.2	60.9	33.6	14.6
0	306.6	177.6	63	37.6	10.4
62.5	1.4	94.4	51.9	27	7.2
125	1.5	0.9	11.7	7.9	1.8

Table 8 Average Ion Density for Emitter N3

Horizontal position in cm	Heights in cm	Average ion density (–1000/cm^3)	
	156.25	218.75	281.25
125	119.4	53	27
–62.5	109.5	59	33.9
0	122.6	80.2	35.7
62.5	158	33.2	3.2
125	1.4	1.4	1.6

Table 9 Average Ion Density for Emitter N4

Horizontal position in cm	Heights — Average ion density (–1000/cm³) 156.25 cm	218.75 cm	281.25 cm
125	120.1	57.8	27.7
–62.5	159	59	27.4
0	160	82	15
62.5	122.4	54.2	1.4
125	1.3	7	1.3

Table 10 Average Ion Density for Emitter N5

Horizontal position in cm	Heights — Average ion density (–1000/cm³) 156.25 cm	218.75 cm	281.25 cm
125	76.6	51.3	16.2
–62.5	117.6	61.3	12.5
0	124	56.7	3
62.5	4.2	0.9	0.7
125	1.3	0.9	0.9

Table 11 Average Ion Density for Emitter N6

Horizontal position in cm	Heights — Average ion density (–1000/cm³) 156.25 cm	218.75 cm	281.25 cm
125	66.6	33.8	1.5
–62.5	102.2	52.9	3
0	100.5	44.6	0.6
62.5	1.2	1	0.5
125	1	0.8	0.4

These data (Figs. 4.5–4.10, Tables 6–11) confirm that the ion emissivity does not depend on the number of fibers but the effective length of fibres. The relative standard deviation for each emitter in each position was obtained from the data analysis. These values did not vary significantly from case to case.

4.23 Multiple Emitters Connected in Series

To evaluate the effect of the emitters connected in series, one N6 type emitter was suspended at the center of the bar and ion measurements were taken with the ion counter placed in horizontal positions of –125, –62.5 , 0, 62.5, 125 and at 156.25, 218.75, 281.25 cm above ground. Exactly the same procedure was followed using the additional N6 emitters suspended at the position shown in Fig. 4.11. Room temperature was 22^0 C. The relative humidity was 39% and the atmospheric pressure was 750 mmHg. The results are shown in Figs. 4.12 to 4.14.

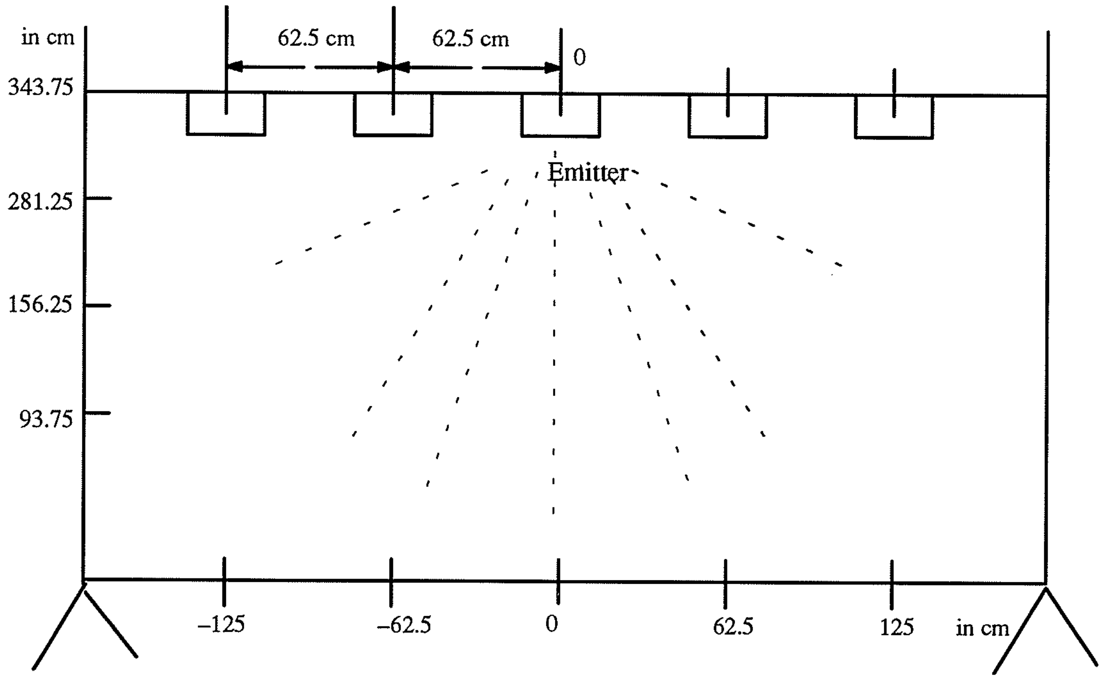


Fig. 4.11 Effect of Emitters in Series

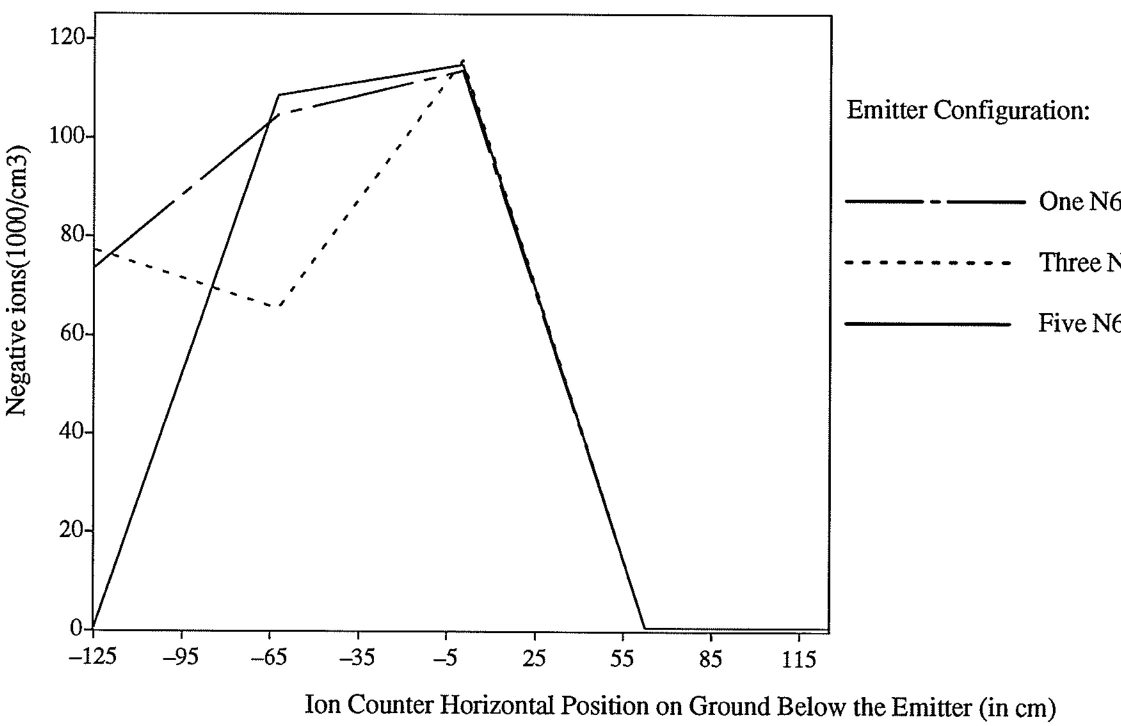


Fig. 4.12 Emitter N6 at 156.25 cm Height

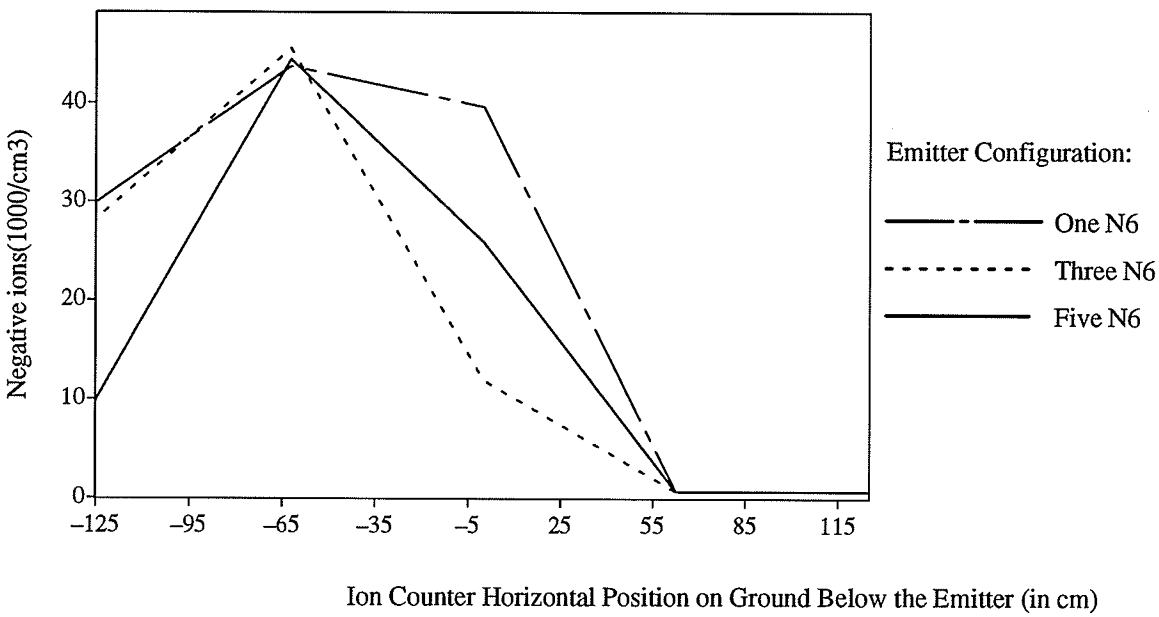


Fig. 4.13 Emitter N6 at 218.75 cm Height

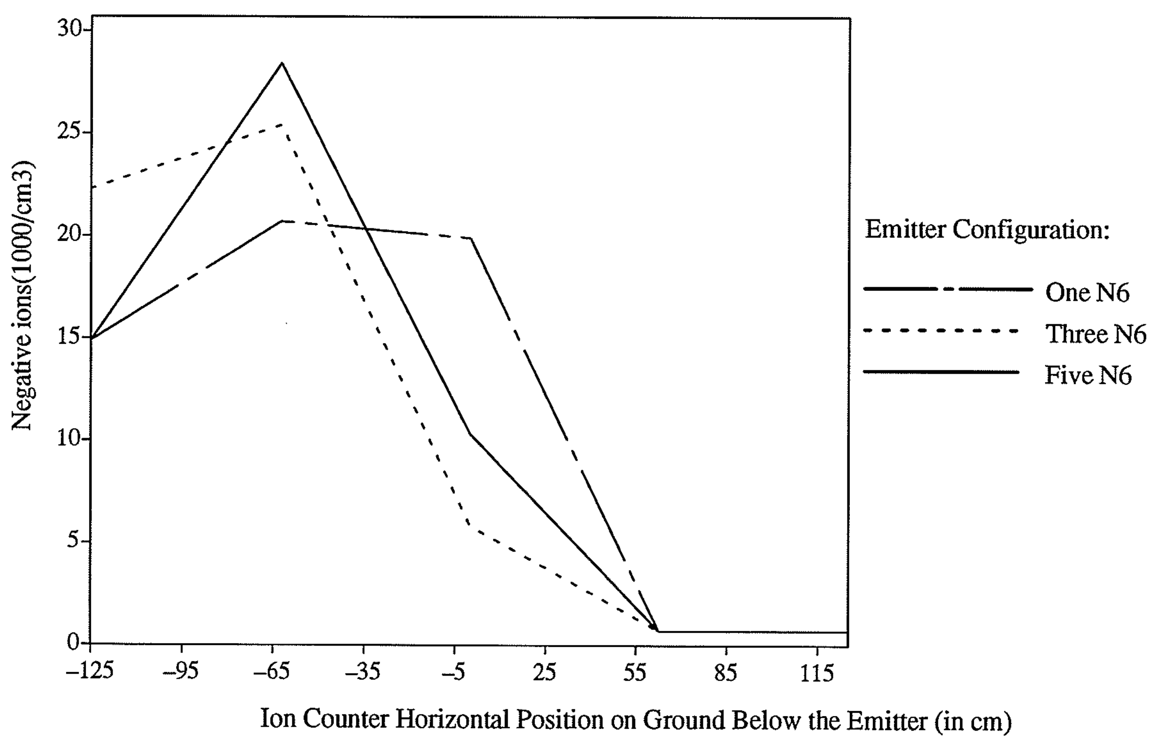


Fig. 4.14 Emitter N6 at 281.25 cm Height

These figures show that using different number of emitters connected in series yields approximately the same maximum ion concentration. However a large number of emitters connected in series yielded a more uniform ion distribution in the air. From the data analysis, the relative standard deviation was calculated as shown in Tables 12 to 14.

Table 12 Ion Distribution and Standard Deviation of Emitters in Series

One N6	Ion number (N) (–1000/cm^3) and Standard Deviation (STD) (%)		
horizontal level / vertical level	156.25 cm	218.75 cm	281.25 cm
	N ± STD	N ± STD	N ± STD
0	114 ± 3.7	40 ± 12	20 ± 11.8
–62.5	105 ± 2.4	44 ± 4.7	21 ± 5.9
–125	74 ± 3.2	30 ± 12	15 ± 21.5

Table 13 Ion Densities and Standard Deviation for Emitters Connected in Series

Three N6	Ion number (N) (–1000/cm^3) and Standard Deviation (STD) (%)		
horizontal level / vertical level	156.25 cm	218.75 cm	281.25 cm
	N ± STD	N ± STD	N ± STD
0	116 ± 4.9	12 ± 107	6 ± 106
–62.5	65 ± 46	46 ± 5.8	25 ± 5.7
–125	77 ± 21.1	28 ± 27.8	22 ± 16.6

Table 14 Ion Densities and Standard Deviation for Emitters Connected in Series

Five N6	Ion number (N) (–1000/cm^3) and Standard Deviation (STD) (%)		
horizontal level / vertical level	156.25 cm	218.75 cm	281.25 cm
	N ± STD	N ± STD	N ± STD
0	115 ± 3.9	26 ± 51.2	10 ± 73
–62.5	109 ± 2.3	44 ± 3.8	28 ± 4.1
–125	1 ± 3.2	10 ± 68.9	15 ± 61.9

The tables show that the standard deviation was the largest when three N6 type emitters were connected in series at (0cm, 218cm) and (0cm, 281.25cm) and was the smallest for one type N6 at position (–62.5cm, 156.25cm).

4.3 Fine Wire Emitters

To compare the emissivity of carbon fibre emitters with fine wire emitters the following experiment was conducted. The arrangement is shown in Fig. 4.15.

In the studies, steel fine wire emitters of various diameters were placed at 84 cm height above ground. The ion counter was placed on the ground directly underneath the emitter. To obtain ion density profile the ion counter was placed at four horizontal locations on the ground, from "–62.5" to "62.5" with a distance interval of 31.25 cm.

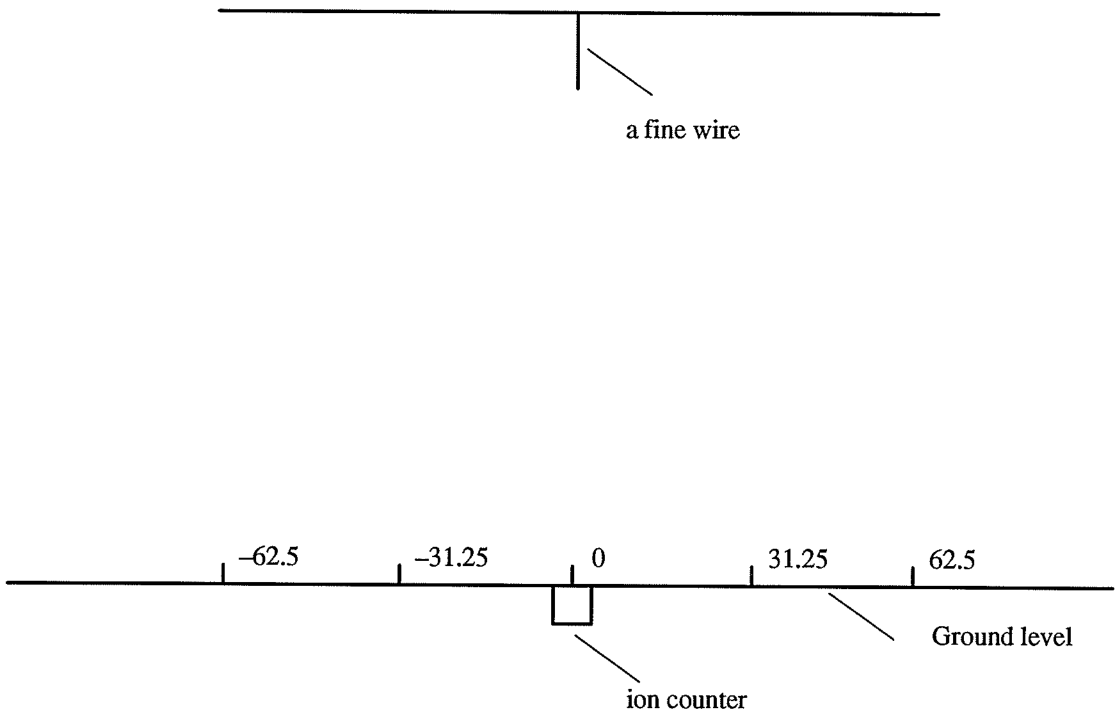


Fig. 4.15 Experiment Setup for Measuring a Fine Wire's Emissivity

4.31 Fine Wire Emitter

A section of wire emitter of 0.122 mm diameter was chosen as shown in Fig. 4.16.

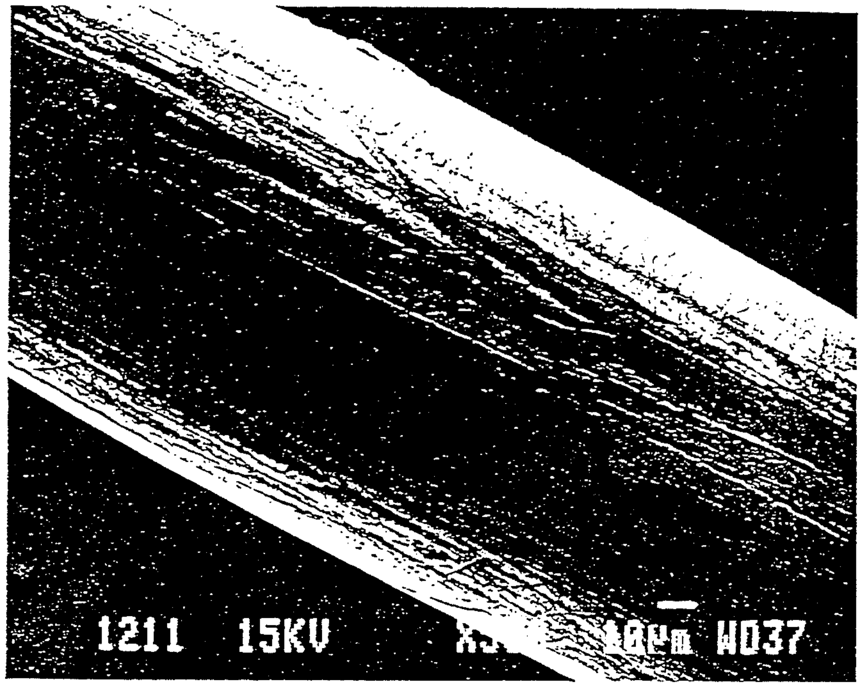


Fig. 4.16 Photograph of a Fine Wire Emitter, 0.122 mm Diameter

During this experiment the room temperature was 22^0 C and the relative humidity was 60%. Atmospheric pressure was 740 mmHg. The ion density measured for this case is shown in Fig. 4.17.

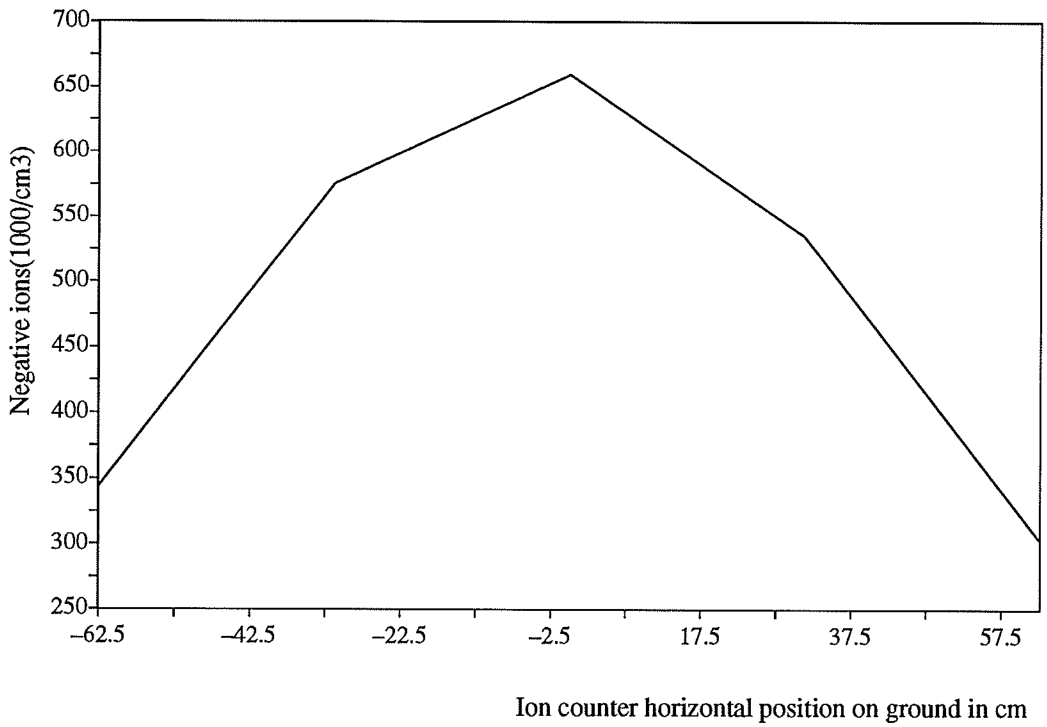


Fig. 4.17 Ion Density for a Wire Emitter

The figure shows that the ion density is the highest directly below the emitter. The ion density decreases gradually on both sides. The effect is due to increased losses resulting from recombination and diffusion with increasing the distance from the emitters.

4.32 Multiple Wire Emitters

To check the ion density produced by multiple wire emitters connected in series the following experiment was carried out. The experimental arrangement was the same as the previous experiment.

At first one wire was suspended 84 cm above ground and the ion density was measured. The ion counter was placed on the ground and measurements were made at points "0", "–31.25", "–62.5", "+31.25" and "+62.5" cm. Two additional wires were then added on each side of the center, the distance between the two wires being 10.5 cm. The ion counter was placed at the same location as in the first step. The room temperature was 22^0 C, the relative humidity was 60% and atmospheric pressure was 740 mmHg. The average ion density and relative humidity for the two cases are shown in Figs. 4.18 and 4.19.

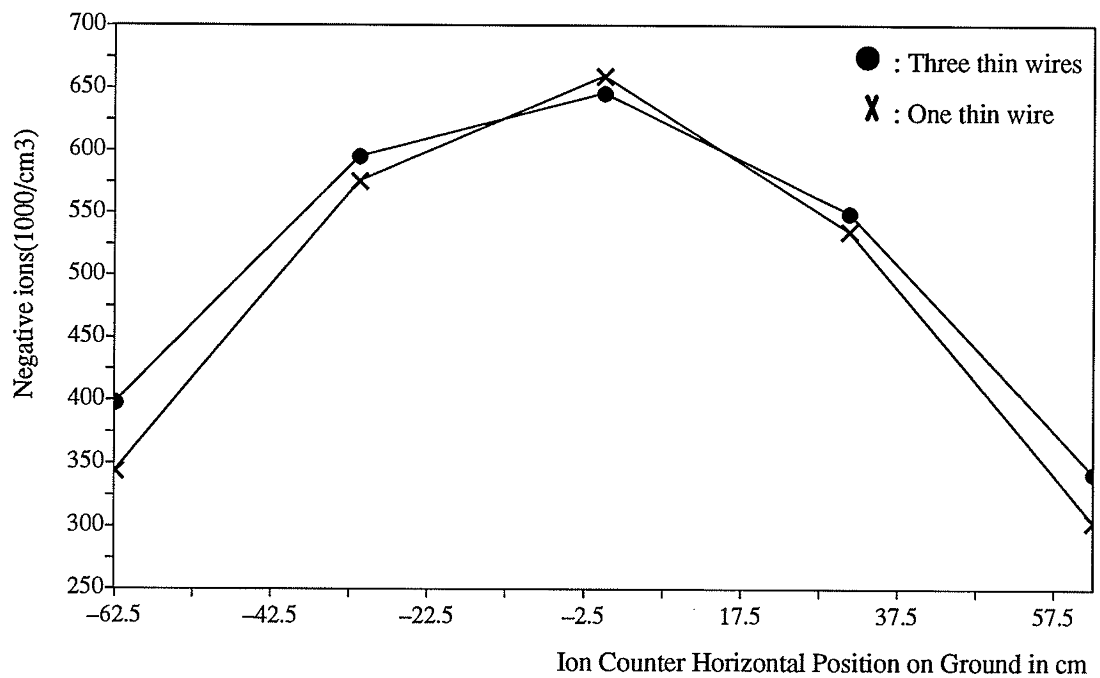


Fig. 4.18 Ion Densities for Multiple Wire Emitters Connected in Series and for a Single Wire Emitter

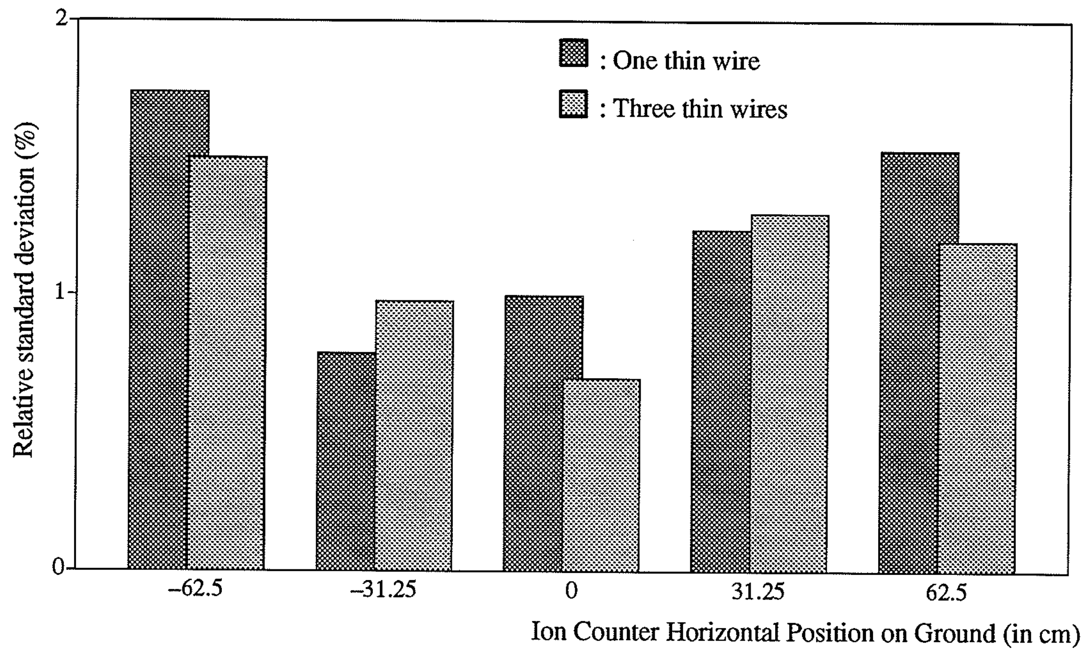


Fig. 4.19 Relative Standard Deviation for Multiple Wire Emitters in Series and a Single Wire Emitter

Fig. 4.18 shows that the ion density for three wire emitters connected in series is higher than that for one wire. These results agree with the data obtained for carbon fibre emitters. However the increase of ion density for multiple wire emitters connected in series is not very striking. In this experiment the distance between two emitters was 10.5 cm. If the emitters are too close to each other their electric fields may affect each other. The relative standard deviation the ion density obtained with three wire emitters connected in series in positions "–62.5" and "62.5" cm suggests that emission is more stable than with one wire. It indicates that the ion density produced by multiple emitters has large stable range.

4.33 Effect of Different Diameters of Wire Emitters

Two wire emitters of the same length (44 mm) with different diameters were suspended at a point 84 cm above ground. The thinner wire's diameter was 0.122 mm, the thicker diameter was 0.255 mm. The ion counter was set directly underneath the emitters and placed at the same location as in the previous experiment in order to obtain the ion density profile for each wire separately. Room temperature was 21^0 C to 23^0 C. Their average ion densities and relative standard deviations are shown in Figs. 4.20 to 4.21.

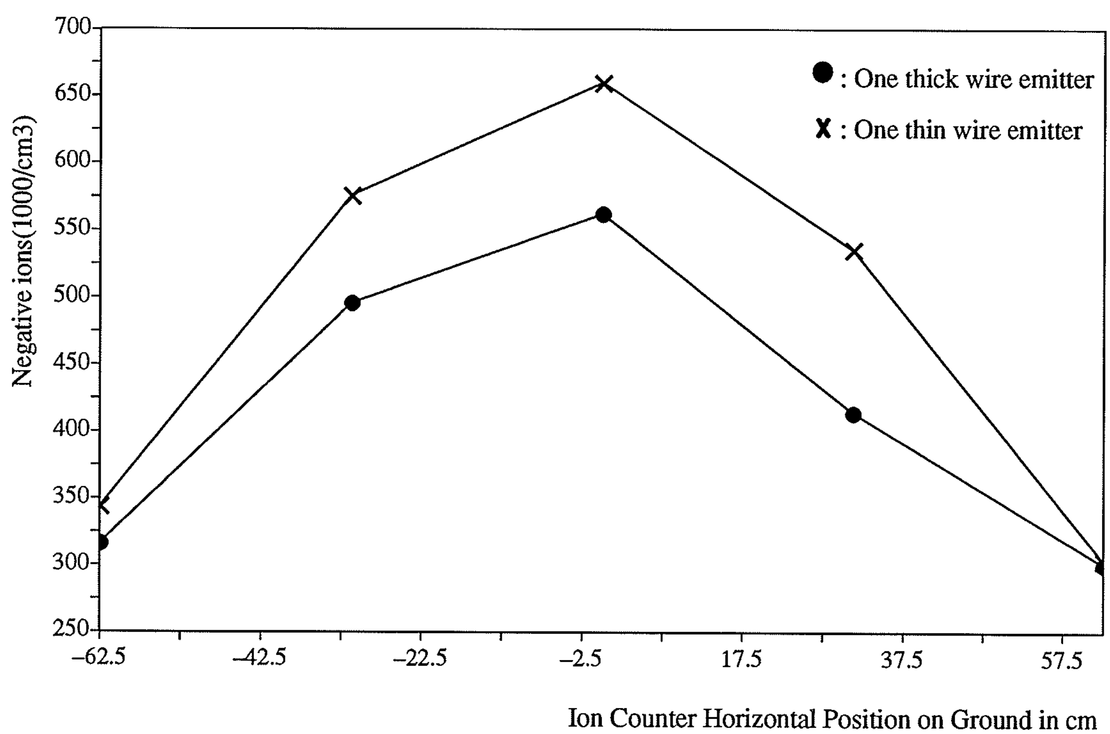


Fig. 4.20 Ion Density Produced by Different Diameter Wire Emitters

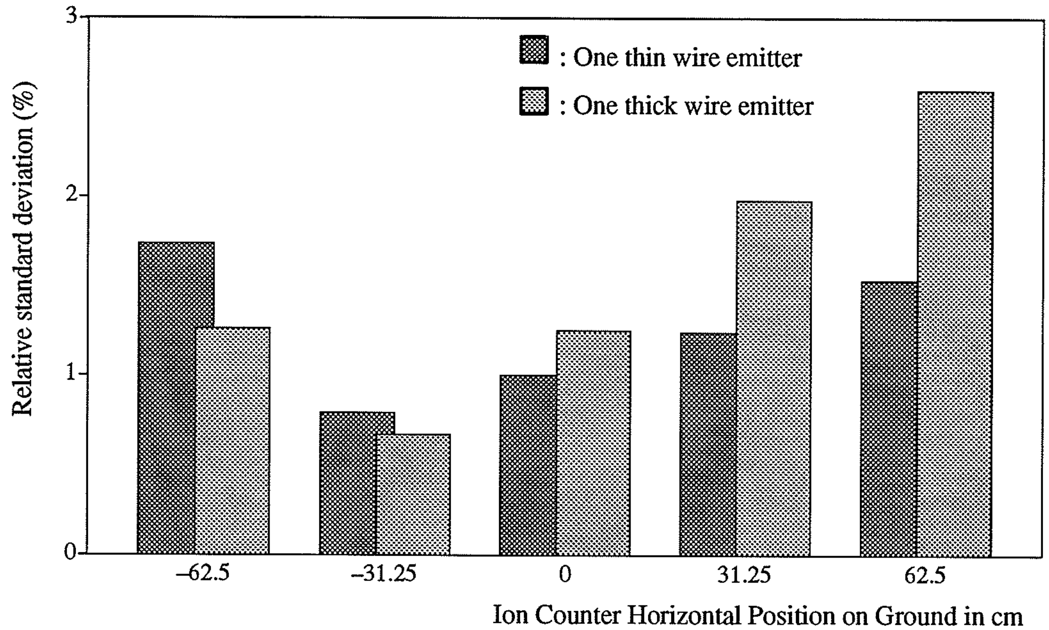


Fig. 4.21 Relative Standard Deviation for Different Diameters of Wire Emitters

From the figures we note that the emissivity for the thin wire emitter is higher than that for the thick wire emitter. This can be expected because the thin wire emitter produces a more non–uniform field than does the thick one so that thin wire electric field strength is higher than that for the thick one. Therefore the ion emissivity of the thin wire emitter is higher. Fig. 4.21 also indicates that the emissivity of thin wire emitter is more stable in most range.

4.4 Needle Emitters

4.41 Sharp Needle Emitter

The ion density produced by a sharp needle emitter was measured. The shape of the needle is shown in Fig. 4.22.

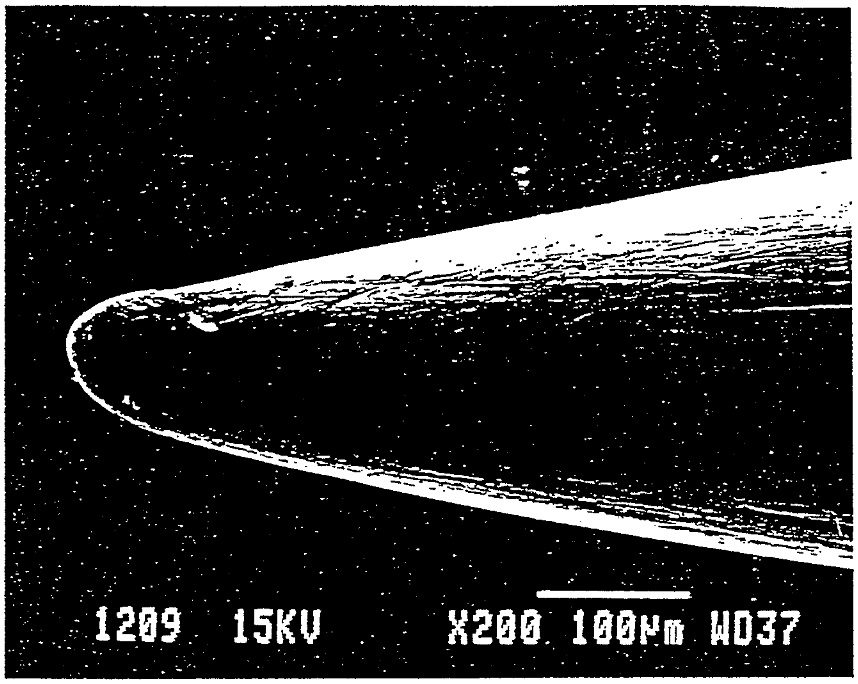


Fig. 4.22 Photograph of a Sharp Needle Emitter with Tip Diameter of 0.008 mm

The experimental setup was the same as the previous one. In this experiment room temperature was 26^0 C. The relative humidity was 54% and atmospheric pressure was 740 mmHg. Ion density for the needle is shown in Fig. 4.23.

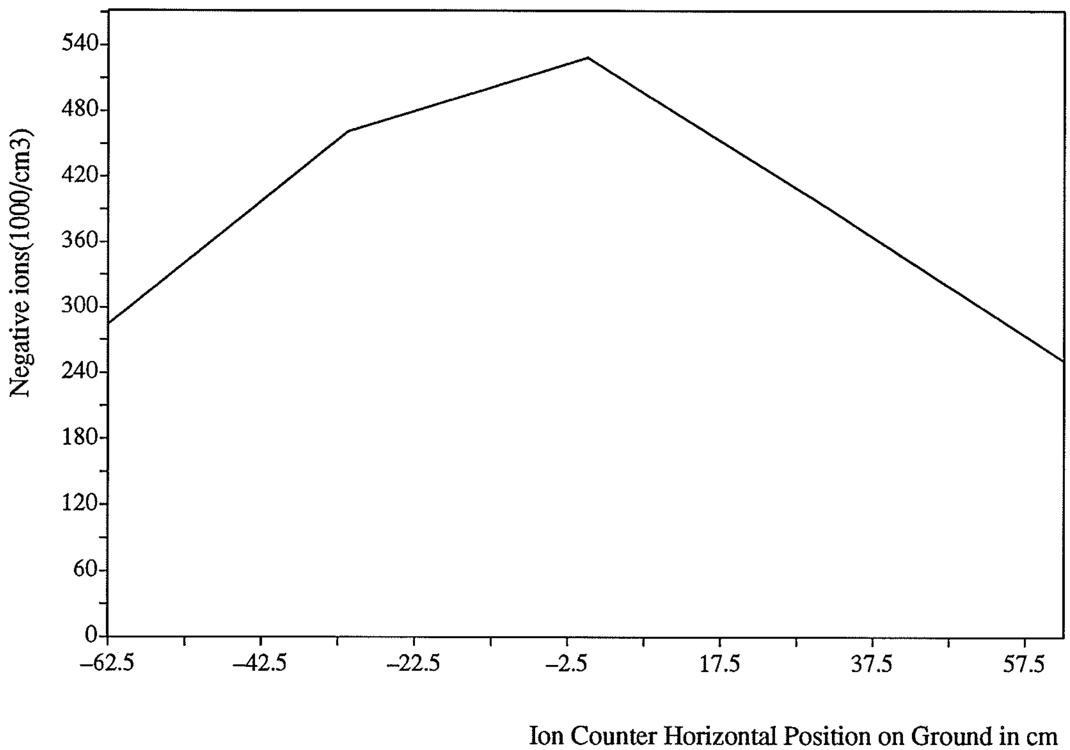


Fig. 4.23 Average Ion Density for a Sharp Needle Emitter

4.42 Different Sharpness of Needles

The emissivity of the emitter depends on the degree of the field non–uniformity. Therefore the ion–generating characteristics of needle emitters with different sharpness should be measurably different. To study this case two needle emitters of different sharpness were selected and their ion densities were measured. Tip diameter of the sharper needle emitter was 0.008 mm and of the blunter was 0.0125 mm. The experimental arrangement was the same as for previous experiments shown in Fig. 4.15. During the experiment room temperature was 22^0 C to 26^0 C, relative humidity was 54% and atmospheric pressure was 740 mmHg.

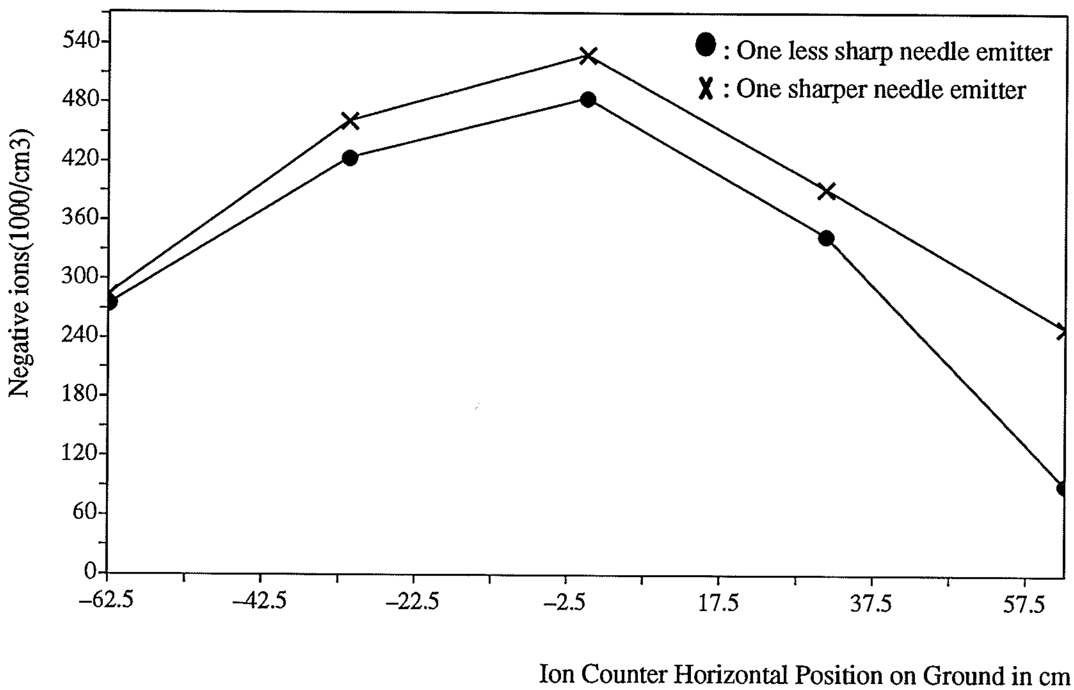


Fig. 4.24 Average Ion Density for Needle Emitters with Different Tip Diameters

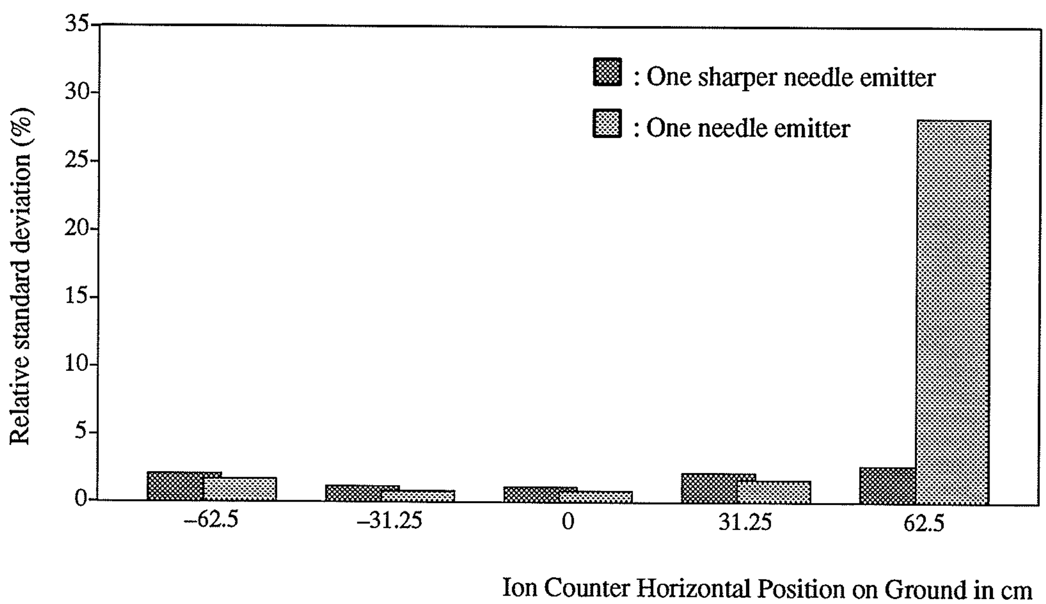


Fig. 4.25 Relative Standard Deviation for Needle Emitters with Different Tip Diameters

Fig. 4.24 shows that the ion density for the sharper needle emitter is higher than the blunter needle emitter. Fig. 4.25 indicates that the relative standard deviation for the sharper needle emitter is nearly constant over a large range of distances.

4.5 Comparison of the Three Types of Emitters

In this project three types of emitters, sharp needle, fine wire and carbon fibre, were studied. Because of their different materials and shapes their ion generating characteristics are noticeably different. The stabilities of three emitters are also distinguishable, Figs. 4.26 and 4.27 show the differences.

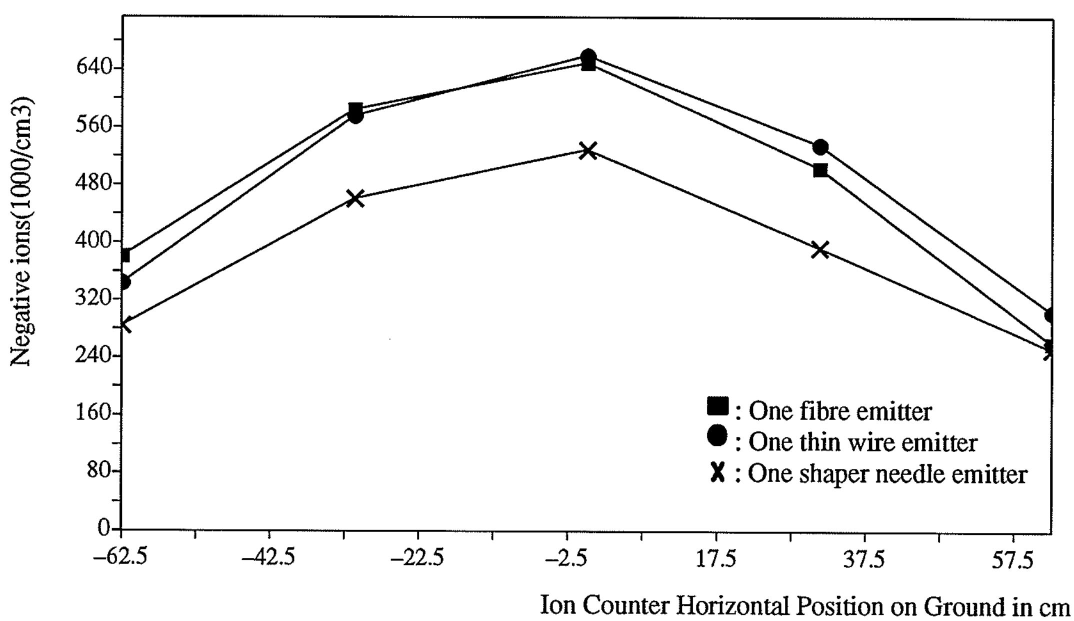


Fig. 4.26 Comparison of Average Ion Density Produced by Sharp Needle, Fine Wire and Carbon Fibre Emitters

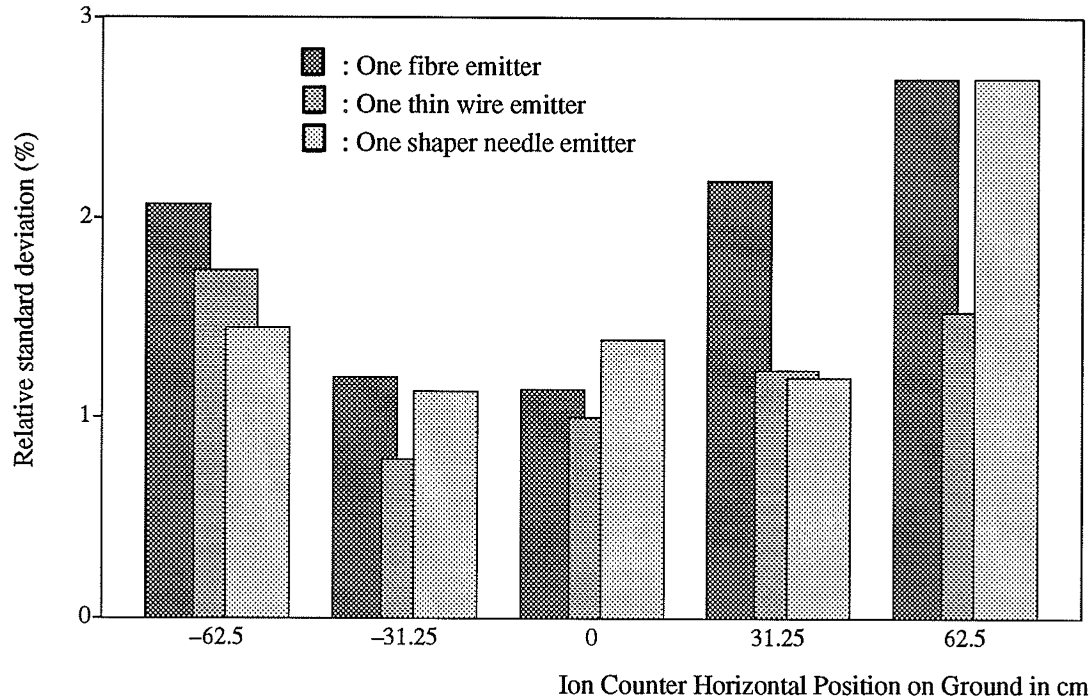


Fig. 4.27 Relative Standard Deviations for Sharp Needle, Fine Wire and Carbon Fibre Emitters

Inspection of the data indicates that the ion densities produced by the three emitters have many qualitative similarities but are quantitatively different. The ion density for a fine wire emitter is the highest and has the widest stable range.

CHAPTER 5
THEORETICAL ANALYSIS

5.1 Ionization and Corona Phenomena

At normal temperature and pressure there are about 1000 pairs of positive and negative ions per cubic centimeter in the atmosphere. These ions result from cosmic rays from the space and radioactive substances in the atmosphere and on the earth [26].

Normally, particles in the atmosphere move in a random pattern. They frequently collide with each other, and change the directions of their movement. Usually the energy transferred during collision is too small to cause ionization. If there is electric field nearby, the field will exert a force on the charged particles (free electrons and ions). These particles will then be accelerated and gain kinetic energy. Since an electron is several thousand times smaller than an ion, it collides with other particles less frequently. Therefore compared with ions, electrons gain more energy between two consecutive collisions. The higher the electric field, the more the energy gained by electrons. If the energy is greater than a specific value (ionization energy of the molecule), upon collision with the electron the molecule can release an electron and become ionized. Electrons with energy lower than the ionization energy may excite particles which then become ionized on collision with other low–energy electrons. The same process will repeat itself and cause an electron avalanche. The electron avalanche combined with other "secondary process" will result in an electric breakdown of the air in a uniform electric field. In an extremely non–uniform field, ionization is restricted to a limited area where the electric field is very high. Consequently, there will not be a breakdown. The electric discharge near the electrode with high field strength in a non–uniform electric field is called corona [26].

In summary, for corona to occur, three conditions must be met: 1) an extremely non–uniform electric field; 2) a sufficiently high electric field strength; 3) a free electron must be available for initiating the electron avalanche. The last condition is easily met since there are many free electrons in the air due to natural ionization.

We know that if the minimum curvature radius of the two electrodes is much smaller than the distance between the two electrodes, the electric field is extremely non–uniform. We know also that maximum field strength is inversely proportional to the curvature radius of the electrode. Thus we can obtain very high field strength with relatively low voltage (several thousand volts) if the curvature radius of the electrode is small enough.

An emitter is actually a sharp electrode (such as a needle, a thin wire or a conducting fibre) whose minimum radius of curvature is very small. The other electrode is the ground. When a negative voltage is applied to the electrode, the high electric field near the emitter produces negative corona. The ions then move under the force of the electric field which exists between the electrode tip and ground and also by the law of diffusion.

Another mechanism for the generation of negative ions is field emission. Field emission occurs when the electric field near the electrode is so strong that it pulls the electrons out from the electrode. When entering a weak electric field area, these electrons may attach themselves to neutral particles, forming negatively charged particles.

The equations describing the negative corona are as follows (diffusion neglected).

$$\nabla^2 u = \frac{en}{\epsilon} \tag{7}$$

$$\vec{E} = -\nabla u \tag{8}$$

$$\vec{j} = ken\vec{E} \tag{9}$$

$$\nabla \cdot \vec{j} = 0 \tag{10}$$

Where u is electric potential. E is electric field strength. n is ion density. e is electron charge. $\vec{j}$ is ion current density and k is ion mobility [35].

If all other variables are eliminated, a third order, non–linear partial differential equation with respect to u is obtained:

$$\nabla \cdot (k\nabla^2 u \nabla u) = 0 \qquad (11)$$

It requires great effort to solve the above equation.

5.2 Electric Field Calculation

Using a finite element method the electric field (corona–free) for a sharp needle emitter was calculated. The calculated electric field around the tip along the vertical and horizontal axes are shown in Figs. 5.1 and 5.2.

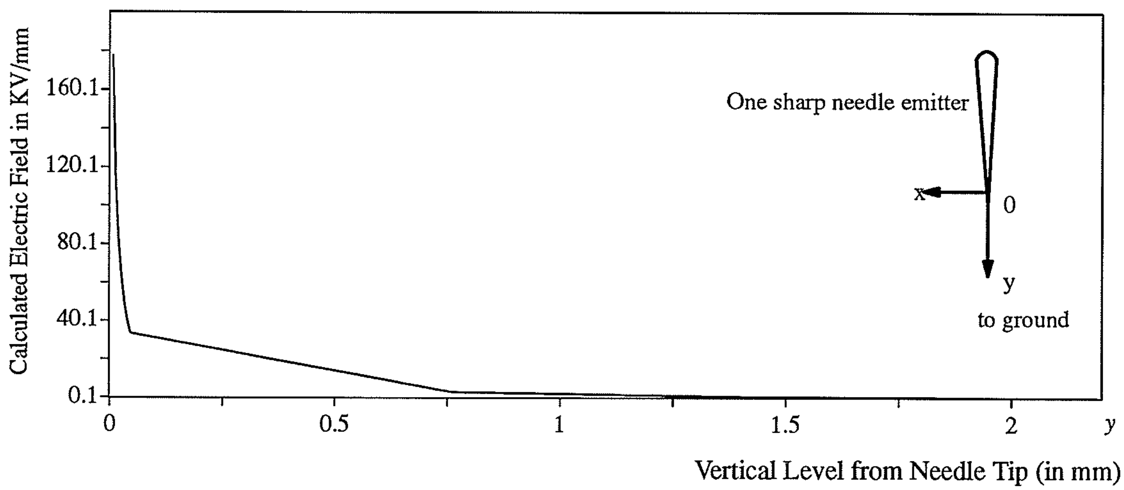


Fig. 5.1 Calculated Electric Field of a Sharp Needle Emitter at Vertical Level

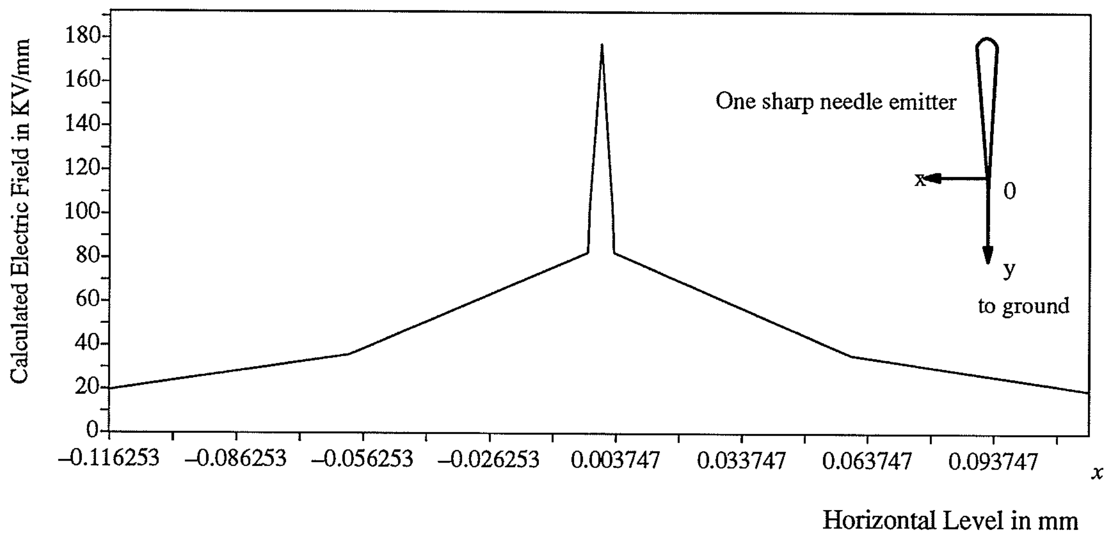


Fig. 5.2 Calculated Electric Field of a Sharp Needle Emitter at Horizontal Level

Fig. 5.2 indicates that the field will be the strongest on the tip and decrease exponentially along the tip to ground. The field at the tip of the emitter will be the highest and will decrease gradually and symmetrically on both sides. Comparing Figs. 5.1 and 5.2, we note that the electrical field along the vertical axis changes more rapidly than that along the horizontal axis. This is understandable since the electric field stress along the vertical axis is more non–uniform than along the horizontal axis under the same applied voltage.

CHAPTER 6
CONCLUSIONS AND SUGGESTIONS

6.1 Conclusions

In this research, the ion density characteristics of air ions with and without the ion–generating system in an indoor environment were investigated. The emissivity of emitters with different materials and the shapes and the efficiency of different emitter configurations and sections of carbon fiber were evaluated. The ionization of the emitters in an indoor environment was determined. The results showed that:

a) In an indoor environment, the ion–generating systems are not importantly affected by the ventilation system. However the experiment in studying the effect of a fan showed that the ionization effectiveness changes significantly when the ionizer is installed inside a duct. Experiments in studying the effects of the shielded room and the wall indicated that grounded materials strongly influence ion concentration in a room. Experiments with gratings placed below the emitter confirmed that the ion density obtained with plastic gratings was the highest. Experiments in which different gratings were suspended above the emitter showed that inserting a plastic grating between the ceiling and the emitter increased the ion concentration.

b) The voltage of the power supply unit used in this study remained constant over a wide range, regardless of the number of emitters connected in series and the heights of the emitters. Though the test was done with 6 emitters, the conclusion can safely be extrapolated to 60–100 emitters.

c) Ionic emissivity does not depend on configuration of the emitters and sections of carbon fibers. However the emitter's position in the room plays an important role in the ion concentration generated. The number of emitters connected in series does not profoundly affect maximum ion concentration produced. However a large number of emitters connected in series yield a more uniform ion distribution in the air.

d) The ionization efficiency produced by three kinds of emitters were found approximately equal. Nevertheless, a fine wire emitter produced more stable ionization over a wide range.

6.2 Suggestions for Further Research

Air ion studies and ion generating system evaluation are still relatively new subjects. However they have very useful applications in many areas. Further research should be carried out.

a) When ionization occurs, some novel chemical particles might be produced in addition to conventionally–understood air ions. Therefore future studies should include these particles and their influence on the environment. These particles should be sought and, if observed, identified. Their effects on the environment should be evaluated.

b) The expense of installing ionizers throughout a building should be justified by evaluation of cost–benefit ratios, according to good engineering practice. The distance between the emitters connected in series, the number of the emitters in a room and the distribution of the emitters significantly affect ionization in a room. Therefore, to obtain high efficiency with an ion–generating system these parameters should be studied and optimized.

c) A more sophisticated mathematical model should be developed for predicting ion distribution of ion–generating systems in a controlled room.

APPENDIX

Table I Variation of Ion Concentration with DC Voltage

DC (kV)	AC (kV)	Average numbers of negative ions (1000/cm^3)
4.6	70	52.4
5.3	80	60.4
5.9	90	92.6
7.1	110	117.8
7.6	120	118.7
8.0	130	138.5
8.3	140	133.4

Table II Average Ion Density and Relative Standard Deviation for a Fibre Emitter with and without a Fan

Horizontal position in cm	Average ion density (N) (–1000/cm^3) and Relative standard deviation (STD) (%)	
	Without a fan (N ± STD)	With a fan (N ± STD)
–62.5	381 ± 1.5	256 ± 11.7
–31.25	584 ± 1.1	415 ± 4.9
0	649 ± 1.4	778 ± 10.6
31.25	503 ± 1.2	426 ± 9.0
62.5	260 ± 2.7	206 ± 45.7

Table III Average Ion Density and Relative Standard Deviation for Multiple Wire Emitters

Horizontal position in cm	Average ion density (N) (–1000/cm^3) and Relative standard deviation (STD) (%)	
	one wires (N ± STD)	three wires (N ± STD)
–62.5	344 ± 1.7	398 ± 1.5
–31.25	576 ± 0.8	595 ± 1 .0
0	660 ± 1.0	646 ± 0.7
31.25	535 ± 1.2	550 ± 1.3
62.5	304 ± 1.5	342 ± 1.2

Table IV Average Ion Density and Relative Standard Deviation for Two Kind of Wire Emitters

Horizontal position in cm	Average ion density (N) (–1000/cm^3) and Relative standard deviation (STD) (%)	
	Thin wire (N± STD)	Tick wire (N± STD)
–62.5	344 ± 1.7	316 ± 1.3
–31.25	576 ± 0.8	496 ± 0.7
0	660 ± 1 .0	562 ± 1.2
31.25	535 ± 1.2	414 ± 2 .0
62.5	304 ± 1.5	301 ± 2.6

Table V Average Ion Density and Relative Standard Deviation for Different Sharpness Needle Emitters

Horizontal position in cm	Average ion density (N) (–1000/cm^3) and Relative standard deviation (STD) (%)	
	shaper needle (N± STD)	needle (N± STD)
–62.5	284 ± 2.1	274 ± 1.7
–31.25	461 ± 1.2	424 ± 0.8
0	529 ± 1.1	485 ± 0.8
31.25	393 ± 2.2	345 ± 1.7
62.5	251 ± 2.7	* 91 ± 28.3

* The value was measured at 1.5 feet.

Table VI Average Negative Ion Density and Relative Standard Deviation for Three Types of Emitters

Horizontal position in cm	Negative ion density (N) (1000/cm^3) and Relative standard deviation (STD) (%)		
	Needle (N ± STD)	wire (N ± STD)	fibre (N ± STD)
–62.5	284 ± 2.1	344 ± 1.7	381 ± 1.5
–31.25	461 ± 1.2	576 ± 0.8	584 ± 1.1
0	529 ± 1.1	660 ± 1.0	649 ± 1.4
31.25	393 ± 2.2	535 ± 1.2	503 ± 1.2
62.5	251 ± 2.7	304 ± 1.5	260 ± 2.7

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