Air Ion Measurement

Air Ion measurement has been primarily the concern of meteorologists and geophysicists. Accurate instrumentation was developed by these scientists many decades ago and as a result, we have substantial knowledge of atmospheric electricity and the forces which control it. Though the devices employed by these early investigators were technically fine instruments, they lacked high sensitivity and reliability so necessary for continuous observations.

The fundamentals of air ion measuring techniques are thoroughly described in books on atmospheric electricity (1,2) and it is not a purpose of this paper to repeat the principles involved except as they relate to specific problems of instrumentation. It suffices to say that the electronic age has produced new devices to ease the problem of collecting accurate data. It is now possible to systematize measuring equipment for simultaneous and continuous recording. In the study of biological and physiological response to air ions it is even more important that complete information on ion density, ion size distribution and ion fluctuations are recorded for careful evaluation. There are so many forces at work to balance physiological changes that air ion effects can easily be missed or mistakenly claimed of occasional point observations are relied upon for interpretation.

A valid criticism of most clinical and biological studies reported has been the lack of sufficient correlating data on air ion density and size distribution. Presumably equipment has not been readily available, but for test results to have any real meaning accurate density measurements must be included as a part of the experiment.

Ion Collectors

Ion collectors are devices for sampling the air and collecting ions in an electric field to form an ion current. The best known ion collector is the Ebert counter designed in 1902. It is patterned after the Zeleny method (3). Figure 1. Norinder and Siksna have described the Ebert counter and its faults in considerable detail (4). Improvements have been made by various investigators, but the basic characteristics remain the same. A similar device which of ten appears in the literature is the Cerdian conductivity chamber (5). Collectors can be constructed to suit particular measuring problems and the type of current sensing meter employed, but not any design parameters are common to all types and may be treated as the same.

The collecting surfaces (cylinder of plates) must be clean and polished to minimize air turbulence, else the sensitivity to measure ion mobility will be seriously impaired. Air velocity must be sufficient to provide a minimum ion current but not so high as to cause turbulence. The polarizing plates or surface must be electrically shielded from the space being sampled and the collecting surface must be similarly shielded and well insulated.

The shape and size of the collector will depend on the selection of air velocity, polarizing potential, and ion mobility range to be measured. Because there are natural fluctuations of ion density (6), too small an air sample will hamper design and limit sensitivity. A practical design limit is a collector which will provide an ion current of $10^5$ ions/sec for sensitivity of 20 ions/cc. A more sensitive collector does not appear to be justified for measuring room air, since the normal density encountered is between 500 to 1000 small ions/sec of each polarity.

This current limitation is determined by the natural fluctuations of density and not by the available current sensing electronic instruments. Ammeters are available to accurately measure ion currents.
as low as $10^{-17}$ amperes (7). This is quite remarkable when we consider that the charge on a single ion is $1.6 \times 10^{-19}$ coulombs (amp sec).

If one is not particularly interested in the normal ion density fluctuations it is quite feasible to accumulate the ion charges on a capacitor and then periodically sample the device to correct the ion current reading of a sensing instrument (8.9). This approach has been used successfully where miniaturization is essential to the experiment and an intermittent sampling is acceptable. The speed of response to small changes is very much less for this type of measuring equipment. Sometimes this is an advantage to provide a smoother record, but as Siksnas and Eichmeier have pointed out complete elimination of these natural fluctuations will hide important characteristics of the ions present and this may lead to erroneous conclusions (10). Particularly in the study of artificial ion sources it is important to observe these fluctuations under various environmental conditions of humidity and air movement.

The factors affecting the design of the ion collector or counter are found in the formula for determining the number of ions per unit volume and the ion mobility. The ion count is determined from the ion current and is expressed by the equation.

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

Where: $N =$ number of ions in one cc of air

$I =$ ion current measured with a micro-microammeter

$q =$ charge on one ion = $1.6 \times 10^{-19}$ coulombs

$v =$ velocity of air in cm/sec

$A =$ area across effective sampling section of ion collector

It can be seen that the smaller the area, $A$, the larger the velocity, $v$, for the same ion current. This is acceptable provided turbulence is avoided at higher velocities. However, a higher velocity means a longer collector to measure ions of lower mobility, because mobility is determined from the equation.

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

Where: $d =$ distance between collecting surfaces

$v =$ velocity of air in cm/sec

$L =$ length of collecting surfaces

$V =$ voltage applied to polarize collector plates

$M =$ mobility of slowest ion collected, assuming laminar flow

If $M$ be small, say 0.005 cm/sec/v/cm, length, $L$ must be large when velocity is high. To avoid this inconvenience it is desirable to keep area, $A$, large and the velocity relatively low, provided the total current collected for any desired mobility is not less than $10^5$ ions/sec.

Another consideration is the relation of $d$, the distance between collecting surfaces, to $A$, the face area. In the usual cylindrical design (Ebert counter, etc.), it is impractical to have more than one surface to collect ions, thus $d$ and $A$ are directly proportional. Where ion mobility distribution is a major consideration of measurement, parallel plate configuration is greatly preferred. In this case $d$ and $A$ can be chosen more freely with as many parallel plates as needed to keep $d$ small, $A$ proportionately larger, and $L$ small. A practical minimum limit for $d$ is about 0.5 cm, otherwise small pieces of lint will interfere with the measurement (contract both plates and surfaces).
There are two examples of ion collectors which differ from the classic Zelen type of Ebert counter. These units are designed to achieve a more practical size and shape without sacrificing sensitivity and to measure a wide range of ion mobilities. One is the Wesix ion collector developed at Stanford University in 1949-50(11), and the other by Schmeer in 1958 at the Institute of Technical Electronics in Munich (12).

The Wesix unit is available in two models; both having the same outward appearance but differ internally. Figure 2. Model IV has a single set of 4 collecting plates 7cm wide × 33cm long. Interspaced between (780cm apart) and on the outside of these collecting plates are 5 polarizing plates of approximately the same size and arranged for an applied battery potential of 11 to 200 volts. The collecting plates are set on pedestal type insulators of polystyrene and these are mounted in a separate compartment to protect them from surface charging (by air friction) and contamination (by airborne dust collecting on the surfaces and reducing the high resistance). The insulator compartment is heated by means of a 20 watts electric element.

The ion collector assembly is enclosed inside a rectangular metal duct, which serves as a guard shield against stray electric fields. The hazard of stray field influence on ion readings can be serious (13). The collecting plates of the Wesix units protrude 2cm in front of the polarizing plates and are positioned with the leading edge 10cm inside the enclosing metal duct. This arrangement minimizes losses of ions to the duct before they can be measured, and at the same time protects the collecting plates from the influence of stray fields. Ions are not subjected to the polarizing field until they have passed the leading edge of the collecting plates. A plot of the electric field of the parallel plates establishes the total loss of ions to supporting structure at less than 3%. The effective cross sectional area is described by the polarizing plates (49cm²), and the effect of the fringing field at the edge of the plates is neutralized by the grounded enclosing duct. This arrangement is a distinct advantage over the usual concentric type collector, which has no fringe guard for the collector electrode.

Air is drawn through the collector and between the plates by means of a small blower. This blower has a capacity of 0.5 cubic meters per minute, but this is reduced by means of a partition orifice to about one half capacity and provides an air velocity of 75 cm/sec. The collector is designed to operate with an air velocity range of 50 to 160 cm/sec. Calibration of the air velocity is a critical feature of this instrument. The performance of the blower must be checked periodically to insure that the unit remains in calibration. Ideally, an air velocity calibration means should be made an integral part of an ion collector.

The Wesix Model V collector is similar except that two sets of collecting plates are provided, one set 7cm long for small ions and a second set with an effective length of 33cm for intermediate size ions. A primary reason to separately measure intermediates size ions (0.3 to 0.005 cm/sec/v/cm) is to explain variations in small ion density. Usually, a decrease in small ion density is caused by an increase in air pollution and consequent rise in larger ion sizes. This two units collector provides a convenient means of simultaneously monitoring two range of ion mobility, an important requirement for clinical studies on the effect of air ions.

The effect of space charge in ion collectors has been note by Siksan and Lindsay (14). Space charge is a problem when the ion density is exceptionally high; i.e. 10⁶ ions/cc, and as a result affects the electric field configuration in parallel plate and cylindrical aspiration condensers. The effect can be neglected when the outer potential applied to the condenser is high (some tens of volts). But if the applied potential is only a few volts as is necessary when obtaining
current-voltage characteristics to determine the mobility distribution of the air ions, the disturbances caused by the space charge must be taken into account.

Whitby, MoFarland and Lundgren have stated that the space charge effect in the Wesix collector is much greater but this appears to be conjecture and is not supported by calculations such as presented by Siksnā and Lindsay. Whitby et al estimated that only one half of the ions are collected at densities greater than $10^5$ ions/cc with 200 volts potential (15).

The Wesix units are designed to be used with commercially available micro-microammeters; a current of $3\times10^{-13}$ amperes corresponds to an ion density of 500/cc full scale. Ability to record the ion density is determined by the stability of the micro-microammeter. For accurate work with a minimum zero drift vibrating reed type instruments are preferred by the meteorologists (16.17).

The absolute accuracy of air ion measurements is primarily dependent on the accuracy with which the resistance of the input resistor of the electronic amplifier can be measured. The various techniques which have been used indicate a probable error of 5% in the value of this resistor under variable room operating temperatures. Consideration of the errors in reading and drift of the recorders increases this error to an estimated 7% (17). The accuracy of the ion collector depends upon this construction and the accuracy of the air velocity measurement. The probable error in measuring the cross sectional area is ±1% and the air velocity is ±2% . Constant voltage (±2%) must be applied to the blower of the ion collector to achieve high accuracy. The overall accuracy of the Wesix ion collectors with the Beckman Model V (V-4120) micro-microammeter is about 12% under favorable conditions (regulated room temperature), or 20 ions/cc whichever is greater.

The response time is also a function of the value of the input resistor of the micro-microammeter. A typical value of response speed for the vibrating reed type of instrument is 4 seconds at $3\times10^{-13}$ amp range. The response to a transient is an exponential decay and a period of about five times. The time constant is required for the transient to decay to a negligible value. Faster response can be achieved at the sacrifice of stability, but this is not a satisfactory solution.

Recorders are available which have high speed response and these have no difficulty in following the current amplifier. Dot recorders, common to multi-channel units, lose much in charting ion mobility ranges and recording fluctuations.

The Schmeer ion counter is of the aspiration type, the aspiration condensers being the same as used in the small ion counter of Michlisen (18), and consists of 19 cylindrical condensers (the outer cylinders have a diameter of 18mm and the inner electrodes 4mm) connected in parallel. Through each condenser system an air flow of 16 liters/sec is maintained by a blower. This ion collector is very compact and yet will provide a continuous ion current of sufficient magnitude for direct reading. The mobility range is limited and the unit is classed as a small ion counter.

**Ion Mobility Measurement**

The importance of ion mobility distribution to clinical research on the effects of air ions has not been fully appreciated. Too many published reports have failed to include measurement data on the mobility distribution of the ions present during the experiment. This fact has made it impossible to fairly evaluate seemingly conflicting observations by competent observers. Stating ion density in numbers per unit volume is not enough; we must also know the approximate size of the ions and, to a degree, the age of air ions (19). If experiments in the future are to be meaningful, we must have assurance on the composition and structure of the ions which are artificially
Small ions are gaseous ions of a few molecules. If the ions are well aged (15 to 20 seconds), and were initially formed in relatively clean air the small positives will most likely be CO$_2$ ions and the negatives O$_2$ ions (20). This is important because Krueger and Smith have observed that these ions are essential for certain physiological changes (21). If the air is not clean initially, the charges will probably encounter a particle during the aging process and the appropriate gaseous ions will not be present even though the small ion count may appear to be satisfactory.

Ion mobility distribution may be determined from measurements with an ion counter by varying the polarizing potential. The range can be extended by also varying the air velocity. As we have seen, it is difficult to design a counter, which will cover the wide range of mobility between 3 and 0.0004 cm/sec/v/cm. Devices have been constructed using two or more stages or collectors in series. One example is the Tversky ion counter (22). But these collectors have not been convenient to use because of their large size and weight. As a practical matter a range of 3 to 0.005 cm/sec/v/cm is sufficient for most work, because the single charge on large ions has such an insignificant effect on the behavior of the larger particle (20 to 100 millimicrons).

Changing the polarizing potential or the air velocity of an ion counter is a tedious procedure if accomplished manually. Ideally it is done using an automatic system which directly records the ion distribution from readings taken at short intervals of time.

A Wesix type ion collector has been modified to achieve this result (23). The first stage collecting plates are used as an ion filter or trap, with the second stage plates electrically shielded to prevent inadvertent ion losses and coupling of the two circuits. A complete mobility spectrum can be recorded every few minutes. The precise time required depends on the speed of response of the micro-microammeter and the number of steps desired. For most amplifier circuits this will be in the order of 10 to 20 seconds for each step. The trap voltage is the best varied in logarithmic steps from 0.3 volts to 600 volts.

Though this arrangement gives a complete trace of the mobility distribution it has the disadvantage of requiring higher speed recording. A system which will provide a direct readout in number instead of chart tracing is the most desirable solution to this problem.

High accuracy of mobility measurement requires a more exact construction of the ion collector. This is because the mobility appears as the square of the distance, “d”, between plates. In the Wesix ion collector, this distance has not been maintained uniform for much better than 5% and hence the collector mobility accuracy is probably no better than 15%. It is recognized that ions enter the collector in random position so that a few larger ions than contemplated will be captured and add to the ion current, and a few of the desired ions will be lost in the ion trap.

Aging of ions is a function of contaminates present in the air, absolute humidity, temperature and barometric pressure. It takes a few seconds for ions from an ion generator to stabilize in size before they are lost to surfaces in the room. In ordinary, unfiltered air gaseous ions will have a short life and become attached to airborne submicroscopic particles.

Observations by Bauhaus (24) illustrate the aging effects of particles on small ions, Figure 3. The effect of prefiltering the air by passing room air through an electrostatic filter and then through an activated carbon pack is shown in comparison with similar air unfiltered before ionizing. In filtered air most of the negative ions have their original mobility, greater than 0.6cm/sec/v/cm. In ordinary air (clean but unfiltered), there is a large group of ions in the mobility range of 0.04 to 0.1cm/sec/v/cm. In this experiment the generated ions were allowed to age for a few seconds in
both cases before sampling. Information of this kind would be missed in using the ordinary ion counter. Even a two stage counter would not have sufficient resolution to detect these two close but distinct groups of ions.

**Survey Counters**

It would be understood that there is also justification for a small ion counter to be used as a portable meter to make field surveys. As long as one appreciates the limitations of measuring small ions only, there is great convenience in being able to check ion generators, suspected ion sources, and even small ion ambient conditions. A meter of this type is not difficult to construct. The counter itself can be as small as 150 cc with a polarizing potential of 22 volts. The dc electrometer amplifier can be quite simple where the device is only used for point measurements and there is ample opportunity to check zero drift.

A portable small ion counter has been built in Munich by Professor Max Knoll’s group and is complete with dc amplifier and battery power for the blower, collector and amplifier. This device measures 20×15×7.5 cm and weight about 3kg (25). This type of instrument can be of great value to the air conditioning engineer. It doesn’t tell all he needs to know but it gives valuable rough information to suggest additional steps for investigation.

Another survey meter which has had applications is the patented target collector (20). This simple device measures small ion rate of flow from ion sources. It is particularly useful in the laboratory for research on bacteria, tissue and plant cells. The target collector is conveniently used with a Hewlett Packard 425A Micro-microammeter. The collector, no longer than a silver half dollar, is attached to a probe on a shielded cable. This unit must be used with care to insure that the collector element does not disturb electric fields which may be present.

**Summary**

Accurate air ion density measurement is essential to the reporting of biological and clinical studies on air ions. The minute and hourly variations which occur with and without artificial ion generation are not yet controllable and therefore must be observed and reported to aid interpretation. Accuracy of 12% is obtainable using electronic amplifier circuits with high stability. Ion mobility is important to properly identify ions and the ion mobility spectrum is a valuable means of describing the quality of air.
References

Communications and Electronics, 1961, pp. 695-698.


a. Unfiltered room air in a clean environment. Note two ion groups.

b. Filtered room air in same environment. High mobility ions only.

Figure 3 Negative Ion Mobility Distribution