

Measurement of Air Ions and Aerosols

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The simplest method for the measurement of air ions is the method of collecting air ions on a test-plate. A test-plate makes it possible to measure the density of the flux of air ions which characterizes the effect of air ions on a surface. (It would be erroneous to consider the concentration of air ions as a measure of the effect of air ions on a surface). The air ion flux density is calculated from the following formula:

$$v \text{ /mm}^{-2} \text{ s}^{-1}/ = 6 \frac{I \text{ /pA/}}{S \text{ /m}^2/}, \quad (14)$$

where I is the current passing through the test-plate and S is the uncovered surface of the test-plate. The current I is measured by an electronic picoammeter or a sensitive galvanometer. In the case of low conductivity and variable field intensity the result must be corrected by taking into consideration the induction current. The relation of flux density to the concentration of air ions is calculated from the formula:

$$v \text{ /mm}^{-2} \text{ s}^{-1}/ = n \text{ /mm}^{-3}/ \times k \text{ /mm}^2 \text{ V}^{-1} \text{ s}^{-1}/ \times E \text{ /kVm}^{-1}/. \quad (15)$$

If the dispersion of air ions from the air ionizer is carried out only by the electric field, field intensity E is approximately equal to the ratio of the voltage of the generator U to the double distance $2r$. In this case the method of collecting air ions on a collector also enables one to evaluate the small ion concentration:

$$n \text{ /mm}^{-3}/ \approx \frac{I \text{ /pA/} \times r \text{ /m/}}{12 S \text{ /m}^2/ \times U \text{ /kV/}} \quad (16)$$

The more precise and better adaptable aspiration method was introduced at end of the nineteenth century by Thomson and

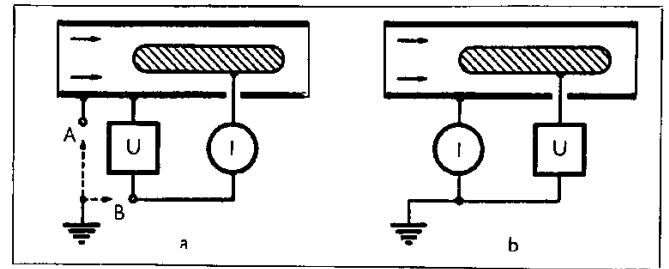


Fig. 1 - Two variants of the skeleton diagram of an aspiration counter of air ions.

Rutherford (1896), McClelland (1898) and Zeleny (1901).

The basic diagram of an aspiration counter is presented in Fig. 1a. As a transducer acts a measuring condenser whose covers are usually coaxial tubes, less frequently — parallel plates. A voltage U of 1 to 1000 V is applied between the covers. The rate of the air-flow under study Φ is of the order of 10^{-5} to $10^{-2} \text{ m}^3 \text{ s}^{-1}$. The charge of air ions that have settled on the inner cover passes through the electrometer I measuring the intensity of the electric current. If one picks up all air ions from the air passing through the condenser, the air ion concentration is determined from the formula:

$$n \text{ /mm}^{-3}/ = \frac{I \text{ /pA/}}{160 \Phi \text{ /m}^3 \text{ s}^{-1}/} \quad (17)$$

In reality, the measuring condenser is not capable of attracting all air ions. Only those ions are completely covered whose mobility exceeds a certain critical value called limiting mobility. Limiting mobility is calcu-

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lated from the formula:

$$k_0 / \text{mm}^2 \text{V}^{-1} \text{s}^{-1} / = \frac{8.85 \times 10^6 \Phi / \text{m}^3 \text{s}^{-1} /}{C / \text{pF} / \times U / \text{V} /}, \quad (18)$$

where C is the active capacity of the measuring condenser. Air ions with mobilities below k_0 are picked up only partially. Therefore, the quantity determined from the formula (17) does not represent the full concentration of any strictly limited group of air ions, and it should be more correctly called the conventional concentration of air ions N . The conventional concentration depends on the limiting mobility. The function $N = N(k_0)$ is a characteristic of the counter. From this function it is in principle possible — by employment of rather complicated methods (Israel, 1957; Tammet, 1967) — to calculate the concentration of any group of air ions as well as their spectral function. Usually one does not succeed in establishing the function $N(k_0)$ with the necessary accuracy.

By choosing $k_0 \geq 200 \text{ mm}^2 \text{V}^{-1} \text{s}^{-1}$, it is possible to measure air conductivity as follows:

$$\lambda / \text{pSm}^{-1} / = \frac{8.85 I / \text{pA} /}{C / \text{pF} / \times U / \text{V} /} \quad (19)$$

The measurement of air conductivity is simpler than the measurement of the air ion concentration since formula (19) does not include the rate of air-flow.

The choice of the earthing point as presented in Fig. 1a is debatable. If one grounds point A, the measurement is perfect, but the electrometer is maintained at a high voltage, which is technically inconvenient. Under these circumstances it may be better to exchange the function of the cover, as shown in Fig. 1b.

The sensitivity and the accuracy of the counter depend above all on the properties of the electrometer. Vibrating reed type electrometers are the best. The quality of the source of voltage is also of importance: the voltage source must be stable throughout the entire period of measurement (instability of short duration must not exceed 0.001 %). The bridge circuit (Erikson, 1921, Reinet *et al.*, 1967) permits a compensation of the instability of voltage but complicates the set-up of the counter.

The aspiration counter is not capable of measuring all degrees of air ion concentration. The rise of the electric field of a space charge in the measuring condenser sets an upper limit to the concentration.

It is necessary to point out that the aspiration counter may distort the distribution of air ions near the generator, particularly if its ionizing power is low.

In addition to the integral method of measurement just described, there are differential methods specially designed for a detailed study of the spectrum of air ions.

Discussion of the theory of aspiration counters and all kinds of calculation formulas were presented by Tammet (1967).

The impulse method of measuring the spectrum of air ions should also be mentioned here (Zwang 1956), but its application is rather specific.

To measure the density of the space charge $\rho = n_+(0, \infty) - n_-(0, \infty)$, the method of filtration with a fibrous filter is used (Imyanitov, 1957; Israel, 1961) while in other instruments an electrofilter is substituted instead (Gunn, 1952).

Apparatus for the Measurement of Air Ions

A survey of the instruments used in measuring air ions may be found in a number of reports (Israel, 1957; Beckett, 1961; Siksna, 1961; Minkh, 1963; Tammet, 1967). The last one gives an exhaustive survey.

The most interesting designs, some of which have not been described in the surveys mentioned above, will be presented here.

To measure the flux density of negative air ions, a light device (weighing 1.5 kg) has been constructed. It has a disk-like test-plate with an area of 0.01 m^2 (Tammet, 1962) and a measuring range of 5×10^2 to $5 \times 10^7 \text{ mm}^{-2} \text{s}^{-1}$. The instrument « Model 403 » produced by ROYCO Instruments, Inc., U.S.A., is also provided with a disk-like test-plate. The area of the collector is 0.0005 m^2 , with a lower measuring limit of $4 \times 10^6 \text{ mm}^2 \text{s}^{-1}$. Devices provided with test-plates are simple and require only a picoammeter or an electrometer.

Adsorbing filters are used to measure the density of a space charge. In the report by

Kitayev (1966) a special filter has been mentioned.

Aspiration counters serve to measure the conventional concentration of air ions. Counters of small and intermediate air ions usually have smaller dimensions than multipurpose counters. Beckett's (1961) paper carries descriptions of two models of air ion counters formerly produced by Wesix, U.S.A. Their minimum limiting mobility is about $0.5 \text{ mm}^2 \text{ V}^{-1} \text{ s}^{-1}$, their minimum conventional concentration is about 0.5 mm^{-3} . One model is provided with a pre-condenser for collection of small air ions.

It must be kept in mind that determination of minimum values of the limiting mobility and of the conventional concentration indicated in this paragraph cannot be accomplished at the same time. In order to reduce the limiting mobility the air-flow

rate must be reduced also. This, however, lowers the sensitivity of the counter.

Air ions counters « Model 411 » and « Model 412 » produced by ROYCO Instruments, Inc., U.S.A., have a mechanism analogous to the previous counters. These counters have a measuring condenser made of parallel plates.

More accurate results can be obtained by a coaxial (cylindrical) measuring condenser. For instance, the counter described by Mendenhall and Fraser (1963) has two coaxial measuring condensers connected separately to the electrometer. Its minimum mobility is approximately $0.2 \text{ mm}^2 \text{ V}^{-1} \text{ s}^{-1}$ and its minimum conventional concentration is about 0.2 mm^{-3} . It can carry out continuous recording. The considerable period of time necessary for its stabilization after a change of voltage is probably due to po-

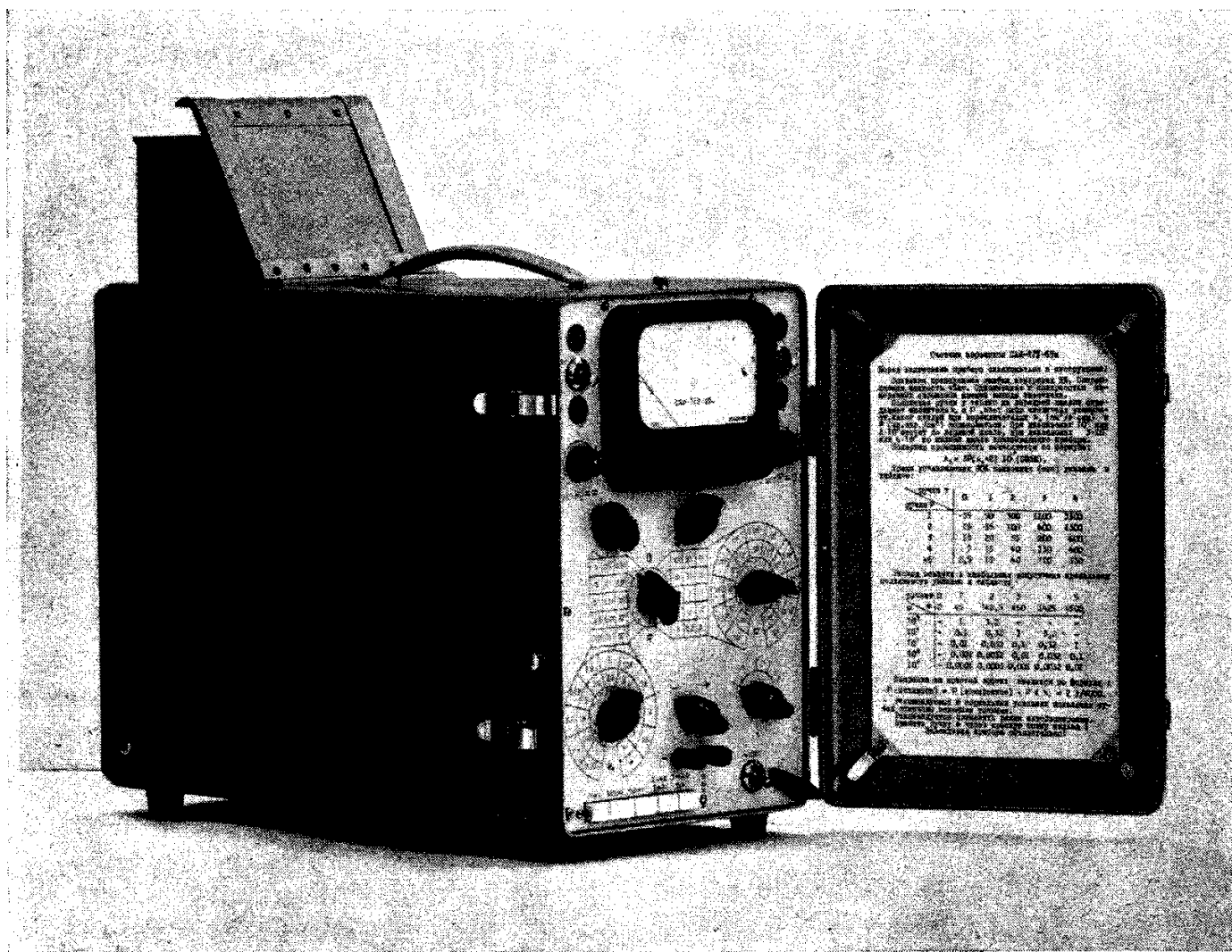


Fig. 2 - Multipurpose counter of air ions.

larization phenomena (Reinet *et al.*, 1967).

A special device is needed for the measurement of the conductivity and the concentration of small ions (Giorgi, 1963).

The report by Hock and Schmeer (1962) carries the description of a counter with nineteen measuring condensers switched in parallel. Its air-flow rate is considerable — $0.016 \text{ m}^3 \text{ s}^{-1}$ — and hence its sensitivity is high. Still, it is impossible to employ a high air-flow rate in the study of low-capacity air ionizers.

Air ion counters affording measurements over a broad range of mobilities, from small to ultra-large air ions, are called multi-purpose counters.

An improved model of a counter (Israel, 1929) is manufactured by Spindler and Hoyer, F.R.G. It contains two coaxial measuring condensers for the measurement of positive and negative air ions respectively. Precondensers are applied to pick up small air ions.

A counter of the type SI-62 (Kitayev and Kloiz, 1963) is being produced in the U.S.S.R. It is provided with two measuring condensers and admits location of the measuring condenser at various distances up to 5 m from the set. The weight (85 kg) and the dimensions of the counter are quite large. Small concentrations of air ions are measured by a mechanical electrometer, large concentrations — by an electronic electrometer.

A portable counter of air ions provided with a vibrating reed electrometer has been constructed at Tartu State University and described by Reinet *et al.* (1967). Improved models of air ions counters have been designed at the same University: SAI-TGU-65 m (Tammet, 1967) (Fig. 2) and SAI-TGU-66. In their design main attention has been given to the convenience of application, reduced weight (up to 11 kg) and increased accuracy of measurements. The range of limiting mobilities is 0.01 to $800 \text{ mm}^2 \text{ V}^{-1} \text{ s}^{-1}$, the range of conventional concentrations is 0.1 to $3 \times 10^6 \text{ mm}^{-3}$. The unit is equipped with a precondenser and adapted for continuous recording with the help of an external recorder. The response time of

the counter can be regulated within wide limits.

Under standard conditions the spectrum of air ions can be determined from the characteristics of an integral counter, as indicated in the previous paragraph. Still, there exist a number of designs of counters which are more adapted for spectral determinations. Counters with a divided condenser (Misaki, 1950); and counters with a divided air-flow (Nolan, 1919) are widely known. Counters provided with both, a divided condenser and a divided air-flow (Erikson, 1921; Hoegl, 1963), are in greater measure adapted for the study of the details of the air ion spectrum.

In regard to the accuracy of measurements one must note that designers of the models of counters do not publish data on the correction of errors in measurements. If a method of measurement is free of methodological errors such as end-effect, etc., the relative greatest error is the sum of errors made in the measurements of the air-flow and the intensity of the ion current as recorded by an electrometer.

Microscopic and Ultramicroscopic Measurement of Electroaerosol Particles

Differences in the behaviour of particles having various parameters in fields of force are used to measure the size and charge distribution of electroaerosol particles.

In the case of microscopic methods, particles are separated in cross fields and settled on slides. The electric charge is determined from the place where a particle settles; particle size is measured with an optical or an electron microscope.

In addition to an electric field, a gravitational field, an air-flow field, an ultrasonic field, etc., can be used as separating fields. The method most frequently used for the measurement of electroaerosol particles is the one based on the precipitation of particles out of the vertical air-flow by means of a horizontal electric field. In this case the actions of the gravitational field and of the air-flow are added up algebraically (Gillespie and Langstroth, 1952). A horizontal electric field is created between the covers of a parallel-plate con-

denser. Aerosols are passed into the condenser through a narrow orifice. The jet is surrounded by a sheet of clean air flowing at the indicated linear rate. The principle described is equal to the principle of separating air ions in a differential counter with a divided air-flow. The description of the respective instruments can be found in the papers by Gillespie and Langstroth (1952); Kitayev *et al.* (1965), etc. The range of measurement depends on a particular design of the instrument. Gillespie and Langstroth measured with their device particles having a radius of up to 7 μm and carrying a charge of 1 to 100 e . The instrument designed by Kitayev and others can be applied to the measurement of particles with a radius of 0.5 to 50 μm carrying charges up to $10^5 e$, including volatile particles of water.

The settled particles (or the traces left by the particles) are usually photographed under a microscope. There exist a number of optical-mechanical analyzers (Schluge, 1960) and optical-electronic analyzers (Walton, 1954) for the measurement of the distribution of the size of the particles on microphotographs or directly on slides. Optical-electronic analyzers (scanning microscopes) are available in Britain: the Casella device produced by Electronics Ltd., the quantitative television microscope put out by Metals Research Ltd., Cambridge, etc. The U.S.S.R. will soon manufacture an optical-electronic analyzer which will permit a direct analysis of particle preparations with sizes of 0.5 to 100 μm at a rate of up to 100 particles per second with an accuracy of particle size measurements of 2 to 5 %.

A detailed description of the methods and instruments used for the automatic analysis of microscopic particles was given by Ivanitsky *et al.* (1967).

When ultramicroscopic methods of measurement are applied, the motion of particles is observed or photographed in fields of force while the speed of particle motion is measured. Particles are visible under dark-field illumination as luminescent points. In this way it is possible to observe and measure also large submicroscopic particles

with a radius of 40 nm and over. The accuracy of measurement of the size and the charge of small particles is limited by Brownian motion.

For the study of electroaerosols the Millikan method of a vertical electric field and the oscillation method of Wells-Gerke and Fuchs-Petryanov (Fuchs, 1955; Green and Lane, 1964) are used.

The Millikan method is especially suitable for physical studies. It was originally developed for determination of the elementary charge. When determining the particle charge, the settling velocity of particles between the horizontal covers of the parallel-plate condenser is measured under the simultaneous action of the electric and gravitational fields or only in the gravitational field. Knowing the particle density and the field intensity and applying the formula of Stokes-Cunningham, it is possible to calculate the radius and the charge of particles. Regardless of the fact that the Millikan method is rather laborious, it is often applied as the most exact method of measuring the particle charge (Blanchard, 1958; Berezyuk, 1966). It is applicable to particles with a radius of approximately 0.1 to 5 μm .

When the oscillation method is used, particles are deposited under the action of the gravitational field, oscillating at the same time in the horizontal alternating electric field between the vertical covers of a parallel-plate condenser. To create an electric field, it is expedient to apply asymmetrical rectangular alternating voltage. This enables one to identify the polarity of the charge. Components of the travelling speed of a particle in the electric and gravitational fields are determined from the photographs of the zigzag trajectories of a particle, and from these components the charge and mass (size) are calculated. Under intermittent illumination it is also possible to determine the sizes of uncharged particles. The oscillation method is simpler than the Millikan method. It is applicable to particles with a radius of 0.1 to 20 μm . The measurement of smaller particles is hindered by Brownian motion, that of large particles is hampered by the inertia of the particles. Many modifications of the above

described instruments are known (Makhotkin and Solovvov, 1960; Uprus *et al.*, 1966). The instrument designed by Gubensky and Fuchs (1958) use a vertical air-flow, slowing the settling of large particles in the electric field. This expands somewhat the range of measurements.

The application of the ultrasonic field (Nieboj, 1958) provides interesting possibilities. However, construction of such devices meets with several difficulties which interfere with their popularization.

Measurement of the Intensity of an Electric Field

An electric field is a factor unavoidably accompanying unipolar air ionization. Even screens cannot remove the electric field since air ions themselves create such fields.

Very often physicists do not speak of the field intensity of an electric field but of the potential gradient. Except for the polarity, these concepts are identical.

The simplest instrument for the measurement of field intensity is a collector-device. As a collector (probe) may serve an α -preparation or a tritium preparation (γ -preparations and hard β -preparations are unsuitable!) which is fixed to a small metal platelet. The collector is attached to a carefully insulated rod and connected to an electrometer having the measuring range of several hundred volts.

If the collector is suspended over a completely flat surface, field intensity is calculated in accordance with the formula:

$$E \text{ /Vm}^{-1}/ = \frac{U \text{ /V/}}{h \text{ /m/}}, \quad (20)$$

where U is the voltage and h is the height of the collector.

Details of the theory of the collector-method may be found in the reports of Lecolazet (1946), Mühleisen (1951) and Israel (1961, 1964).

Collector-devices are usually designed for the measurement of the atmospheric electric field. The details of a portable device suitable for measurements carried out in a closed room is described in a paper by Giorgi (1963).

Another simple instrument for the measurement of field intensity is the Wilson plate. An insulated metal plate located in the same plane as the surface over which field intensity is measured is connected to an electrometer. The plate is screened by an earthed disk and is grounded for a moment, then the screen is removed. After such a procedure the reading of the electrometer is proportional to field intensity. A detailed description of the Wilson method was given by Israel (1961).

The most perfect instrument for the measurement of field intensity is the so-called field-mill, which is considerably more complicated than an ordinary collector or a Wilson device.

In its principle the field-mill is a mechanized Wilson device. The test-plate is intermittently closed and opened by a rapidly rotating screen recalling a wind-mill. The alternating voltage induced on the test-plate is measured by a phase-sensitive electronic voltmeter. The alternating current of the test-plate may also be rectified and is usually measured by a galvanometer (Chalmers, 1953).

The miniature field-mill is the most suitable device for the measurement of the electric field in a closed room or in a laboratory. Details of the technique of measurement and a description of the design of a field-mill were published by Imyanitov (1957) and Israel (1961).

Devices for measuring field intensity also enable us to measure the density of the surface charge. Having determined the field intensity E over a conductive surface, we find that

$$\sigma \text{ /pCm}^{-2}/ = 8.5 E \text{ /Vm}^{-1}/. \quad (21)$$