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ON THE METHODS OF COUNTING AIR IONS

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Abstract – It is expedient to earth the outer cover of an air ion counter. In this case the neutral terminal of a sensitive electrometer gets a voltage. If the neutral terminal is earthed, the electrometer should be connected with the inner cover by a coupling capacitor. The disturbing influence of voltage fluctuations is removed by a balanced bridge scheme. In the case of a sensitive electrometer the ionic current may be measured by voltage drops arising on the resistor shunting the electrometer. It is even better to compensate the ion current by the current passing through a high resistance, by maintaining the input voltage of the electrometer in the vicinity of zero. The most essential parts of the structure of a counter are its insulators, which must be protected from the direct action of outside air and the precipitation of aerosol particles. The parts surrounding the insulators must have a voltage equivalent to that of the inner cover. An attempt has been made to meet these requirements in constructing a portable ion counter fed by alternating current. The indicating instrument mounted on the switch-board directly shows the ion concentration. Changes in ion density can be automatically registered by means of a recording external millivoltmeter connected with the counter.

Zusammenfassung – Es ist zweckmäßig, das äußere Meßkondensatorrohr des Aeroionenzählers zu erden. In diesem Falle wird man der Nullklemme des empfindlichen Elektrometers die entsprechende Spannung geben. Wenn die Nullklemme geerdet ist, muß der Elektrometer mittels eines Trennungskondensators mit dem inneren Meßkondensatorrohr verbunden sein. Die störende Wirkung der Speisespannungsschwankungen wird mittels der Brückenschaltung beseitigt. Im Falle der Anwendung des empfindlichen Elektrometers ist es möglich, den Ionenstrom nach dem Spannungsabfall an den Enden des Hochohmwiderstandes zu messen. Noch besser würde es sein, den Ionenstrom mit einem durch Hochohmwiderstand geleiteten Strom zu kompensieren und die Eingangsspannung des Elektrometers dabei nahe der Nullinie zu halten. Die wichtigsten Bestandteile des Zählers sind die Isolatoren, die gegen die direkte Wirkung seitens der äußeren Luft und der Sedimentation der Aerosolteilchen geschützt sein müssen. Die den Isolator umfassenden Details sollten eine gleiche Spannung zu der des inneren Meßkondensatorrohrs haben. Unter Berücksichtigung aller dieser Gesichtspunkte wurde ein tragbarer, vom Wechselstromnetz gespeister Ionenzähler konstruiert. Das Meßgerät an der Vorderplatte zeigt direkt die Ionenkonzentration an. Der Ionisationsverlauf kann dabei mittels eines äußeren selbstschreibenden Millivoltmeters automatisch registriert werden.

Résumé – Il est rationnel de mettre à la terre le revêtement extérieur du condensateur de mesure des aéroions. Dans ce cas, on donne une tension à la borne-zéro de l'électromètre.

La borne-zéro étant mise à terre, l'électromètre doit être lié au revêtement intérieur par un condensateur de séparation.

L'influence perturbatrice des variations de la tension d'alimentation est éliminée par un montage en pont.

En cas d'utilisation d'un électromètre sensible, il est possible de mesurer le courant ionique d'après la chute de tension de la résistance ohmique élevée. Il est mieux encore de compenser le courant d'ions par un courant dirigé à travers la résistance ohmique élevée, en maintenant la tension d'entrée de l'électromètre près de zéro.

Les détails les plus importants du compteur sont les isolateurs qui doivent être protégés contre l'influence directe de l'air extérieur et de la sédimentation des particules d'aérosols. Les détails avoisinant les isolateurs doivent avoir la même tension que le revêtement intérieur du condensateur de mesure.

En tenant compte de toutes ces exigences, on a construit un compteur d'ions portatif, alimenté par le secteur en courant alternatif. L'appareil de mesure relié à la plaque avant indique directement la concentration des ions. Il est possible d'enregistrer automatiquement les variations de l'ionisation a l'aide d'un millivoltmètre enregistreur.

The measurement of the density of air ions in different conditions is a complicated physical and technical problem, and explains why very many papers have been devoted to the problem of constructing ion counters. In spite of this fact, the properties of the existing counters do not adequately meet the actual requirements. The excessive size of the constructed devices, their complicated and troublesome handling, and their poor reliability must be regarded as their most important drawbacks, and these are revealed particularly clearly when the charge density of electroaerosols is to be measured.

Hence we set ourselves the task of constructing a reliable multiple-purpose counter of small size which can easily be handled and used in carrying out research into bio-climatological and geophysical problems as well as those of artificial aeroionization.

THE DESIGN OF THE COUNTER

In most counters of air ions the outer cover of the cylindrical measuring condenser gets a voltage and the inner cover is connected with an electrometer the neutral terminal of which has been earthed. This measuring method—the charging method—is however, not quite appropriately named as the charge on the measuring condenser actually decreases in the course of the measuring process. For these reasons the design to be described has been designated by us as that of the earthed inner cover. The drawback of counters with an earthed inner cover is the end-effect (Lenard and Ramsauer 1910; Itiwara, 1931; Scholz, 1931; Israel, 1932; Siksna, 1950), which can essentially distort the results of measurement. Various electrostatic safeguards have been used to remove the end-effect (Swann, 1914; Reimers, 1940; Yunker, 1940; Komarov, 1961), but they render the structure of such counters more complicated. Electrostatic safeguards may produce disturbing side-effects. Thus, for instance, in the case of the Swann safeguard, which has found the widest application (Swann, 1914; Gish, 1932), the cross-section of the air current entering the condenser widens, rendering the air current turbulent with a lower volumetric velocity than with a tube of uniform cross-section (Schlichting, 1959). In the case of a counter with a Swann safeguard the conditions necessary for the study of the spectrum of the ion mobilities have not been fulfilled (Tammet, 1960). This fact has interfered with the determination of the ion mobilities by means of a counter provided with a Swann safeguard (Scholz, 1935). One of the principal defects of electrostatic safeguards is the diminished reliability of the counter on account of the strong electric field arising in connection with an electrostatic safeguard, and this is of particular importance in the case of counters of heavy ions.

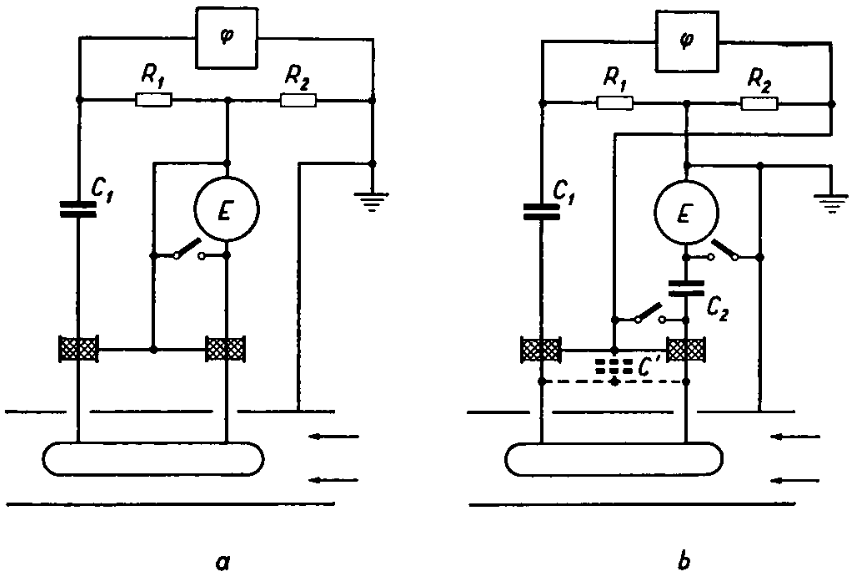

FIG. 1. The designs for a counter of air ions

In some counters of older types (Ebert, 1901; Gerdien, 1905) the scheme of an earthed outer cover is used along with an earthed neutral terminal (the discharging method). Such a scheme, however, is rarely applied nowadays owing to its low sensitivity and the resulting long measuring time.

The end-effect can also be avoided in counters with an earthed outer cover if a sensitive electrometer is used (McClelland and Kennedy, 1912; Weger, 1935). The defects of the scheme with an earthed outer cover, however, are the complexity and the parasitic capacity of the measuring condenser.

The scheme with an earthed outer cover where the neutral terminal of the electrometer has a voltage equivalent to that of the inner cover is best (Lenard and Ramsauer 1910, Baranov, 1925; Israel, 1931; Nolan and Nolan, 1935; Gubichev, 1955; Reinet, 1958, 1959). Such a scheme differs from that with an earthed inner cover only in the choice of its earthing point.

In the case of a design with an earthed cover and a sensitive electrometer, the end-effect can easily be avoided. Experience shows that the giving of voltage to the neutral terminal of the electrometer does not bring about any insurmountable technical difficulties (Baranov and Kravchenko, 1934; Weiss and Steinmauer, 1937; Schaffhauser, 1952; Reinet, 1959). The greater complexity of the structure of the counter resulting from the insulation of the electrometer is compensated by a greater simplicity of the structure of the measuring condenser.

The neutral terminal of the electrometer can also be earthed in a counter with an earthed outer cover and a sensitive electrometer if the inner cover is connected with the electrometer through a special coupling capacitor (Tammet, 1962 b).

It is necessary that the feed voltage of the measuring condenser in a counter with sensitive electrometer should have a high stability. The difficulties that may arise may be overcome by means of a bridge scheme with an auxiliary capacitor (Erikson, 1921; Komarov, Kuz'menko and Seredkin, 1961; Reinet, 1962), in which the fluctuations in the voltage of the feedsource do not affect the measuring results.

The designs of the counters recommended by us are shown in Fig. 1. In Fig. 1a arms of the bridge layout, which are balanced for possible changes in the voltage, are formed by the capacity of the measuring condenser C, the capacity of the compensating condenser C_1 and the resistances R_1 and R_2. In Fig. 1b the coupling capacitor C_2 has been introduced, which makes it possible to earth the neutral terminal of the electrometer. This arrangement is desirable in the case of a particularly high voltage of the measuring condenser. In the case of the scheme with a coupling capacitor, changes in the feed voltage can exert an influence on the readings of the electrometer only through the capacity C' of the insulators. In the scheme under consideration this influence is neutralized by the balanced bridge network formed by the capacities C' and C_1 and the resistances R_1 and R_2.

THE MEASUREMENT OF THE ION CURRENT

The convenience of handling the counter and the precision of measurement depend on the method of measuring the ionic current precipitated on the inner cover.

As a rule, voltage decrease $\Delta\varphi$ in a measuring condensor with an insulated inner cover is recorded in the course of a given period of time denoted by Δt and the current is calculated from the ratio $I = C_0\Delta\varphi/\Delta t$, where C_0 is the total capacity of the insulated system. The periodic grounding of the electrometer is performed either by hand or by a mechanism. If the measuring results are recorded automatically (Langevin and Moulin, 1907; Saks, 1956), one obtains a disconnected recording curve, which is not always to be recommended. The method of the condenser voltage decrease resembles the method of compensation with care of a current induced above capacity (Nolan and Nolan, 1935; Thellier, 1936). An advantage of the compensation methods is their greater degree of precision.

In the case of the shunting resistor method (Nordmann, 1904) the power of the current can be calculated from the ratio of the voltage of the electrometer to the resistance connected in parallel to the electrometer. An advantage of this method is the possibility of steady recording, as it is not necessary to carry out the commutations. By contrast, in the design with a coupling capacitor, the measuring condenser has to be recharged from time to time, short-circuiting the input of the electrometer during those periods. The current indicator functioning by the method of a shunting resistor has a somewhat greater inertia than the indicator operating by the method with the decreasing condensor voltage, but the high sensitivity of modern electrometers makes it possible to reduce inertia adequately for usual measurements. The shunting resistor method resembles the method of compensation with the current passing through the resistor, in which case the electrometer is used as a null indicator. Vacuum tube electrometers and dynamic electrometers make it possible to perform compensation automatically by means of an electrical feedback.

Of electrometers, the dynamic ones are the most satisfactory, for the direct reading and the possibility of simple automatic recording facilitate the handling of the counter. Vacuum tube electrometers with a conductive input have also been used (Schaffhauser, 1952), but their degree of sensitivity and especially that of stability are considerably lower. Of mechanical electrometers, the Lindemann type of electrometers have shown themselves most expedient (our model CГ – 1 M resembles them).

THE STRUCTURE OF INSULATORS

Amongst the most essential units of the measuring condensor of a counter are the insulators of the inner cover, and the quality of insulation is the most critical factor in guaranteeing the reliability of a counter. The number of insulators ought to be kept at the minimum. Experience shows that the inner cover of a measuring condenser of average size can be fixed securely enough by means of two insulators.

The parts on which an insulator rests should have the same voltage as the inner cover, otherwise leakage current is inevitable, causing essential errors in measurements (Israel, 1931). It is necessary to use double insulators. They may be constructed with one metal interlayer (Langevin and Moulin, 1907; Gockel 1917; Nolan and Nolan, 1935; Reinet, 1958, 1959). There is an additional advantage in mounting the insulators in a separate tube insulated from the outer cover and having a voltage equivalent to that of the inner cover (Reinet, 1962). To avoid the errors which may arise with the polarization of the insulators due to a change in the voltage of the measuring condenser, it is necessary to shield the surface of an insulator from the electric field. It is required to shield not only the insulators bearing the inner cover but also all other insulators as the charges on their surfaces may affect the readings of the electrometer by electrostatic induction.

The surfaces of the insulators must be protected from the direct effect of a current of outside air, or else the aerosol particles may precipitate on the surface of the insulator and destroy the insulation. Insulators must be mounted above the measuring condensor so that gravity will not aid the precipitation of aerosol particles. The choice of the material of an insulator is of great importance. Fluoroplast (Teflon) has proved to be the best material for insulators for its electrical properties and dampproofness, but the unsatisfactory mechanical properties do not permit of using it everywhere. Another kind of insulating material is polystyrene, which is mechanically durable, lends itself easily to processing and is not inferior to amber in electrical properties.

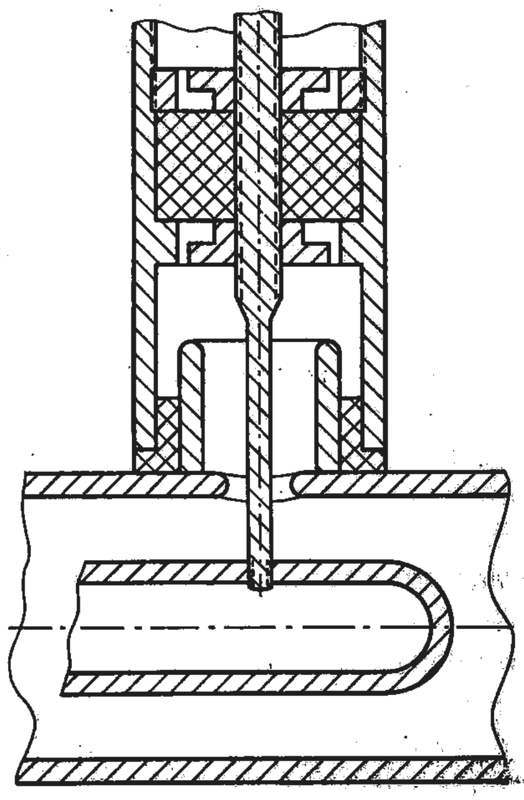

FIG. 2. Structure of the insulator of the inner cover of the measuring condenser

A design for a set of insulators fulfilling the above-mentioned requirements is given in Fig. 2. The insulator is mounted in a tube insulated from the outer cover and having a voltage equivalent to that of the inner cover.

DESCRIPTION OF THE PORTABLE COUNTER

The general requirements touched upon above have been taken into account in the construction of a multiple-purpose counter. This counter (size $53 \times 33 \times 24$ cm) is fed by alternating current. The limiting range of mobility can be selected in the region of $0.0009 - 2.6$ cm^2/v. There are five regions with a linear scale for the measurement of the ion concentration, the concentrations corresponding to swing being 1000–10,000,000 e/cm^3. In the case of higher concentrations measurement would be interfered with by the electric field of the space charge of the air in the condenser (Siksna and Metnieks, 1953; Tammet, 1962a). The ion concentration is read directly on the scale of the indicating instrument. The counter can be connected with any type of recording millivoltmeter by means of which the course of the ion concentration in time can be steadily recorded.

The basis of the design of the counter is represented in Fig. 1a. The measuring condenser is cylindrical, the radius of the inner cover being 1 cm and that of the outer cover 1.95 cm. The length of the inner cover with hemispherical ends is 40 cm; the effective capacity of the condenser is 30.4 cm. At the end of the condenser where air enters it, the outer cover is 6 cm longer than the inner cover to avoid the end-effect. The inner cover is fixed on two insulators the structure of which resembles the one shown in Fig. 2. Connection with the electrometer has been effected through one insulator block, a cylindrical multicover compensating capacitor C_1 with an air dielectric mounted in the upper end of the other insulator block. The capacity of the compensating condenser has been chosen so as to be equivalent to the effective capacity of the counter. A rectifier with a simple vacuum tube stabilizer supplies the voltage. In order to decrease disturbing voltages, capacitors with a capacity of 0.1 μF have been connected in parallel to resistances R_1 and R_2. The voltage of a measuring condenser can be regulated within the limits of 1 v–300 v, roughly by means of a potential switch, and more precisely with the help of a potentiometer. The indicating instrument indicates voltage value and limiting range of mobility. The polarity of the ions to be measured is selected by means of a switch which, at the same time, performs the interchange of the output terminals of the electrometer.

The air-current is sucked through the measuring condenser by means of a ventilator provided with a synchronous motor. A rotameter is used to measure the volumetric velocity of the air current. The nominal volumetric velocity is 1000 cm^3/sec. When heavy ions are measured, the volumetric velocity is reduced to 100 cm^3/sec.

The actuating device of the electrometer is a dynamic condenser. The alternating signal obtained from it is amplified by means of a multistage vacuum tube amplifier 95 dB. The amplified signal is detected in the synchronous ring detector. The detected direct voltage is smoothed and is transmitted to the vacant terminal of the high-ohmage resistor connected with the inner cover. Polarity and the factor of voltage division is so chosen as to give rise to negative feedback with a depth of 30 dB. The electrometer regulates the current passing through the resistor so that the voltage on the input of the dynamic condenser would be in the vicinity of zero. To carry out the function of regulation, it is necessary that the dynamic condenser should have a low cue voltage not exceeding 5 mv. The current of the ions precipitated on the inner cover is compensated by the current passing through the resistor which is equivalent to the ratio of voltage applied to the resistor to resistance. The voltage applied to the resistor is measured with an indicating instrument the readings of which are proportional to ion density.

To change the sensitivity of the counter, high-ohmage resistances are exchanged by a region switch. In the most sensitive region the current corresponding to swing is 1.6×10^{-13} amp. When using resistance $10^{12}\ \Omega$, the voltage drop necessary to compensate the ion current is 0.16 v. For higher levels of measurement the voltage drop remains the same, only resistance value being changed. The inertia of the counter can be regulated by means of filters to be inserted in the feedback circuit. To reduce disturbances, the time constant chosen for the most sensitive region is 50 sec, for other regions the time constant is smaller.

The stability of the zero point of the electrometer depends on the quality of the dynamic condenser. We have used dynamic condensers constructed by O. Saks. Using such electrometers the drift of the zero point within 6 hr does not exceed 1 per cent of the most sensitive region of the counter. In measurements of longer duration the zero point has to be checked periodically and, if need be, it has to be adjusted.

Since the neutral terminal of the electrometer has been given the voltage of the measuring condenser, the electrometer together with its amplifier must be well insulated from the ground. At the suggestion of V. Reeben, another synchronous detector has been used to connect the external measuring instrument with the electrometer. This detector has been insulated from the amplifier by means of transformers. As both the synchronous detectors have the same structure, the outer self-recording measuring instrument has been given a voltage proportional to the ion concentration. The outer measuring instrument can be earthed, which, however, does not interfere with measurements.

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