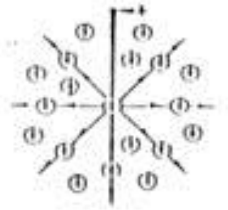
NIELS JONASSEN



IONIZATION

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A LITTLE HISTORY

Almost three centuries have passed since W.Wall in 1708 made the first known observation of the fact that some processes in the atmosphere are electrical by nature by noting that the sparks one might draw from amber rubbed in a suitable manner “seems in some degree to represent thunder and lightning”.

This idea of Wall’s was pursued by several well known scientists, foremost among these Benjamin Franklin who in 1750 suggested an antennae to be placed in a high tower. When a thunder cloud passed the tower one should then be able to draw electric sparks from the antennae. The (regrettable) fact that no sufficiently high tower was at hand in Philadelphia at that time caused the French scientist Dalibart to be the one (in 1752) to prove the identity between a lightning discharge and an electric spark. I should be mentioned, however, that B.F one month later, without knowing Dalibart’s experiment, repeated this in his famous kite experiment, and, no surprise, with the same result.

On the other hand, maybe Ben Franklin was lucky, when on considers the fate of his contemporary, Professor Richardson, in St. Petersburg (Leningrad), who a few years later was killed when lightning struck the “antenna” he had mounted in front of him on his desk.

During the next century and a half atmospheric electric processes were investigated in great detail and by the end of the 19th century the following model was more or less accepted. An electric field exists in the (lower) atmosphere, normally directed towards ground indicating the presence of a negative surface charge on the earth. It was believed that the earth actually had a net charge, and since the air was also considered a perfect insulator, charge could only be transported to or from the earth in connection with evaporation of water vapour, rain (negative charge to the ground).

This simple model seemed to fit observed changes in the field reasonably well, but already as early as 1785 Coulomb had noticed, that an insulted charged body would eventually loose its charge when it was left alone surrounded by atmospheric air. He suggested this effect to be caused by an attraction of oppositely charged dust particles or water vapour from the air, and even if this explanation is rather insufficient, it does contain the certain conductivity. The importance of this observation, however, was not realized, and neither was a similar observation by Mateucci (about 1850), and it was not until the (independent) investigations by Linss and Schuster around 1890 that it was accepted that atmospheric air is not a perfect insulator.

The question of the nature of the mobile charge carriers, necessary for rendering the air conductive, however, gave rise to another question. Why does the negative charge on the earth not become neutralized, as positive charge is brought to the surface by the electric field? A simple calculation would show this to happen in less than an hour, and yet the charge does still appear to happen in less than an hour, and yet the charge does still appear to be there. The answer is that we have not mentioned a very important factor, the thunderstorms.

In a very summaric way we can give the following presentation of what is usually called the atmospheric electric circuit, Figure 1.

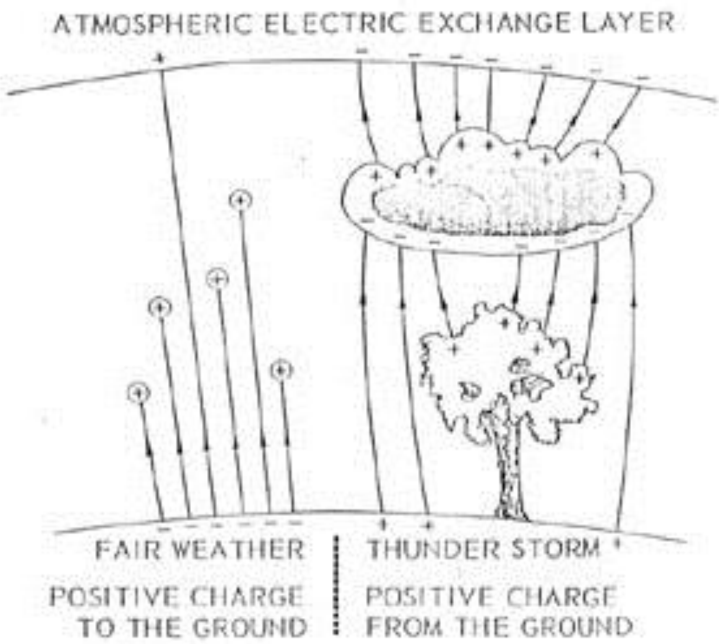

Figure 1. The atmospheric electric circuit.

To the left are shown fair-weather conditions, where the field is directed towards ground an thus will bring positive charge to the surface. Most of the field lines end on positive space charges in the lower atmosphere, while some extend all the way to the so-called atmospheric electric exchange layer (about 60 km up), the lower part of the ionosphere. The necessary field distribution is maintained by the thunderstorms, shown in the right hand side of the figure. A thunderstorm has (normally) a negative basis and a positive top thus bringing negative charge to the ground. The (downward) fair-weather field is approximately 100 – 200 $V*m^{-1}$ while the opposite field under a thunder cloud may be some 10,000 $V*m^{-1}$. The total number of thunderstorms active at any given moment may be about 2000 and the total current to (and from) the earth about 1600 A, which on the other hand only amounts to about $3*10^{-12}$ $A*m^{-2}$ in fair-weather regions.

And let us now turn to the question of the charge carriers, the atmospheric ions.

ATMOSPHERIC IONS

An air ion is formed, when a neutral oxygen or nitrogen molecule looses an electron and is left as a singly charged positive elementary ion. Within less than a microsecond the electron will combine with (usually) another neutral molecule forming a singly charged negative elementary ion, Figure 2.

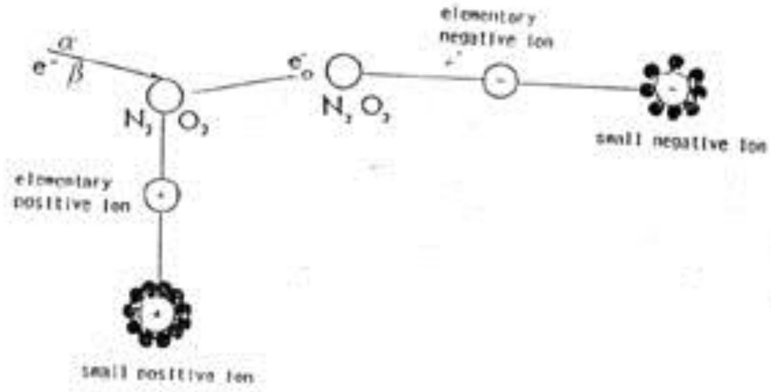

Figure 2. Air-ionization

Small ions

Both polarities of elementary ions will within a fraction of a second by polarization bind a number of 10-20 molecules (water, nitrogen oxides and others) round itself forming a molecular cluster. When we talk about ions, we are usually only referring to these small ions.

Large ions

Any atmosphere will contain aerosol particles or condensation nuclei in numbers from a few thousand to several hundred thousand per cm3. These are particles or molecular clusters with radii from maybe 10nm to about 1 m. If a small ion collides with a condensation nucleus the two may form a so-called large ion.

Ion mobility

The quantity most suitable for characterizing the electrical behaviour of an ion is its mobility. If an ion with a charge e is exposed to an electric field with the strength $\underline{E}$, it is per definition acted upon by an electrical force $\underline{F}$ given by

$$\underline{F} = \underline{E} * e \qquad (1)$$

The result is, however, not as one might expect an accelerated but a uniform motion with the constant velocity $\underline{v}$ given by

$$\underline{v} = k * \underline{E} \qquad (2)$$

The factor of proportionality k is called the mobility of the ion. Its unit is $m^2V^{-1}s^{-1}$.

The ion will actually get an acceleration E*e/m, where m is its mass, and move in the direction of the field with increasing velocity. After a distance equal to the mean free path it will collide with (normally) a molecule, loose all its field energy and field velocity, and start all over again. Hence the apparent uniform motion.

Small ions are found to have mobilites in the range $1*10^{-4}$ to $2*10^{-3}$ $m^2V^{-1}s^{-1}$ and large ions in the range $3*10^{-8}$ to $8*10^{-7}$ $m^2V^{-1}s^{-1}$. Sometimes the range in between is also populated. These ions are called intermediate or Langevin-ions.

IT has often been discussed if atmospheric ions are distributed at discrete mobilities or more or less uniformly over the whole range of mobilities

Small negative ions seem to have mobilities very close to $1.8 – 2*10^{-4}$ $m^2V^{-1}s^{-1}$ and small positive ions about 1.2 -1.4*10-4 $m^2V^{-1}s^{-1}$, The difference probably reflecting a difference in the number of molecules in the cluster. Large ions on the other hand may occupy whole mobility bands depending upon the nature and size distribution of the condensation nuclei available.

ION SOURCES

An air molecule may receive the necessary ionization energy either from a colliding particle or from a quantum of electromagnetic radiation energy.

“Natural air ions are (in the lower atmosphere) predominantly produced by radiation from radioactive materials in the soil, in building materials and first of all in the air (radon and its airborne daughter products). Although all three types (alpha, beta and gamma radiation) can ionize the air, in practice only alpha radiation needs to be considered.

RADIOACTIVE IONIZATION

Alpha particles are emitted from a decaying radioactive atom with energies in the order of 4 to 8 MeV (or 6 - $13*10^{-13}$ J). On its way through the surrounding air an alpha particle will knock off electrons from neutral oxygen or nitrogen molecules, Figure 3, at the expense of about 34 eV per successful collision.

After having travelled a distance from 2 to 7 cm the alpha particle has lost its energy (and velocity) and produced about 200,000 ion pairs along its track.

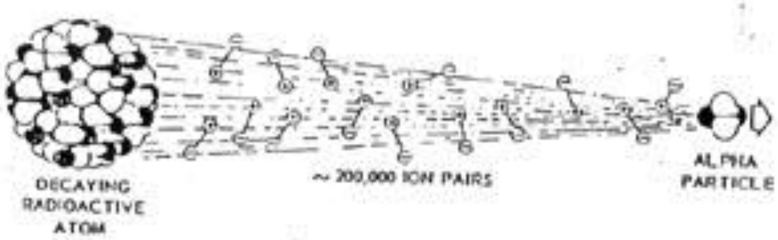

Figure 3. Ionization by alpha radiation

This mechanism of ion production can also be utilized technically, as will be explained later, but the most commonly used method of producing air ions is, however, based on the effect of electric fields.

FIELD IONIZATION

If the air is exposed to an electric field the ions (caused by the natural radiation) will move in the field and collide with (neutral) molecules after having travelled the mean mean path, characteristic for the ions. One might expect this to cause ionization in the same manner as with collisions between alpha particles and molecules. The energy of the ions at the end of the mean free path is, however, not, even at very high field strengths, high enough to knock off an electron. The electrons freed by the natural radioactive ionization, will of course also move under the action of the field, and although they over the same distance receive the same energy as any other particle carrying a single elementary charge, the mean free path is so much longer for an electron, that it, when exposed to an electric field of about $3*10^6$ Vm^{-1} (with plane electrodes and at atmospheric pressure), is able to ionize molecules of the air. The electron being knocked off the molecule will also be accelerated and ionize and so on in the whole region, where the field strength exceeds the critical so-called break down field strength.

Field ionization is usually achieved by keeping a set of sharp points or thin wires at high potential (2-20 kV) with respect to some counter electrode, which may even be the walls of the room.

The break down field strength E_0 has the following values
For points

$$E_0 = (300 + 18/\sqrt{r})*10^4\ Vm^{-1} \qquad (3)$$

And for wires

$$E_0 = (300 + 9/\sqrt{r})*10^4\ Vm^{-1} \qquad (4)$$

Where r is radius of the points and wires respectively (in m).

It appears that the break down field given by (3) and (4) is higher than for a parallel electrode system, but because of the field deformation caused by point and wire electrodes, the necessary voltage is much lower than would be the case with parallel plates. Usually the voltage of the electrodes (points or wires) are kept at such a value, that E0 is exceeded in a region of some mm from the electrodes, Figure 4. In this region we then have so-called corona discharge where ions are formed and separated by the field. If the voltage of the electrodes is positive the negative ions will move to the electrode and become neutralized here while the positive ions will be repelled and move away from the electrode, possibly aided by an air current.

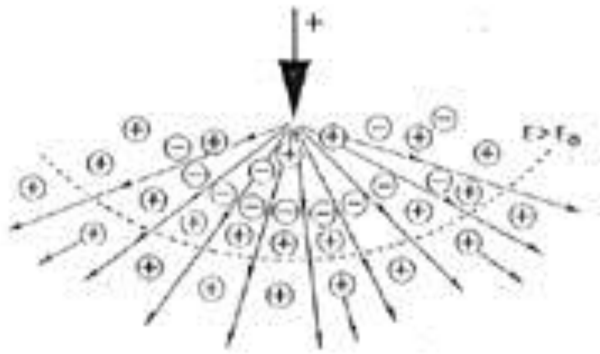

Figure 4. Electric field ionization

The necessary field at the electrodes may, however, also be supplied by the charge to be neutralized, as it will be explained later on (passive ionizers).

REMOVAL OF IONS

An ion has a limited lifetime. It may be moved by an electric field to some surface where it may become neutralized. It may combine with oppositely charged ions or particles and hence cease to exist as an ion, or in the case of a small ion combine with aerosol particles and then either be neutralized or become a large ion, and in both cases no longer exist as a small ion. Figure 5. The rate of combination is proportional to the concentrations of the combining species.

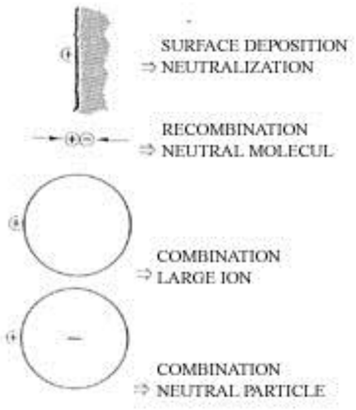

Figure 5. Removal of ions

Let us for example consider a room with a small ion concentration of say 1000 cm^{-3} and a low aerosol concentration of similar magnitude. If now a candle or a cigarette is lit in the room, the aerosol concentration may almost momentarily increase to maybe 100,000 cm^{-3} and the small ion concentration decrease to maybe 50-100cm^{-3}, because the small ions have combined with the aerosol particles created by the combustion processes.

The total ion concentration, on the other hand, may hardly have changed.

But a most important quantity, the conductivity, has.

CONDUCTIVITY

Suppose an atmosphere has an ion concentration of n ions per unit volume with a mobility kj and each carrying a single elementary charge e. If an electric field $\underline{E}$ is established, a current will flow in the direction of the field with the density (current per unit area, Am^{-2}), $\underline{j}$, given by

$$\underline{j} = e*n*k*\underline{E} \qquad (5)$$

or

$$j = \lambda*\underline{E} \qquad (6)$$

This is **Ohm's law** (in differential form).

The quantity

$$\lambda = e*n*k \qquad (7)$$

is called the conductivity of the atmosphere (unit $ohm^{-1}m^{-1}$).

If the ions are distributed with respect to mobilities according to an function of frequencey f(k) in such a way that the concentration dn of ions with mobilities from k to k+dk is given by dn = f(k)*dk the conductivity is given by

$$\lambda = e * \int_0^\infty k*f(k)*dk \qquad (8)$$

Now suppose the atmosphere has a concentration n of small ions with the mobility k_1 and the same concentration n of large ions with the mobility k_2, both species carrying an elementary charge e. The conductivity is then

$$\lambda = e*n*(k_1 + k_2) \qquad (9)$$

Since $k_1 \approx 1000*k_2$, we see that if all the small ions are combining with neutral particles to form large ions, the conductivity will decrease with a factor of (almost) 1000, although the total ion concentration is still 2*n.

Both positive and negative ions contribute to the conductivity, but it should be kept in mind, that when ionized air is used for neutralizing static charges, positive ions can only neutralize negative charges and vice versa.

It is therefore convenient to introduce the polar conductivities, i.e. the conductivities due to positive and negative ions respectively.

In case of an atmosphere with the concentration n^+ and mobility k^+ of positive ions and n^- and k^- of negative ions the polar conductivities are (with singly charged ions)

$$\lambda^+ = e*n^+*k^+ \quad (10)$$

and

$$\lambda^- = e*n^-*k^- \quad (11)$$

λ^+ and λ^- are sometimes misleadingly called the positive and negative conductivity.

ION GENERATORS

Ion generators have been used extensively for many years in the textile, plastic and paper industry for neutralizing charges on fibers or sheet materials. The devices used are normally divided into passive, electrical and radioactive ionizers.

PASSIVE IONIZERS

A passive ionizer is in principle just a row of grounded (metal) points, placed a few centimetres from the charged material, Figure 6.

The field from the charge will be deformed by the points and may here exceed the break down field strength, as given by Equation (3), resulting in a corona discharge. Ions of the opposite polarity will move towards the charged material and partly neutralize its charge.

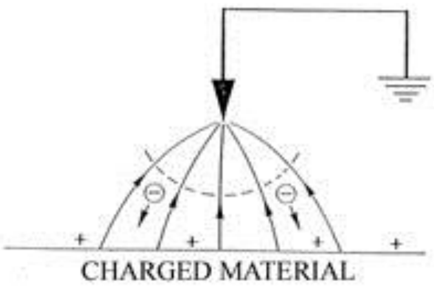

Figure 6. Passive ionizer

Passive ionizers function equally well with positive and negative charges, but they suffer from the short-coming, that the corona discharge stops at a certain charge level, and so the rest charge is not neutralized. They are therefore primarily used where the problem is to remove large annoying charges, and where a minor rest charge is acceptable.

ELECTRICAL IONIZERS

In cases where a more or less complete neutralization of the charges is essential electrical ionizers are often used. Like the passive ionizers they consist of a row of points placed parallel with the charged material, but in this case the points are connected to a voltage source in order to make ionization possible even at low charge density on the material. The voltage source is often an ordinary transformer (about 5 kV), Fig. 7, which will alternately produce positive and negative ions in a fraction of each half period, determined by the voltage and the radius of the points. If the charged material is moving past the ionizer, the neutralization may thus be incomplete, and a DC-voltage may instead be used. If the charge on the material is always negative a voltage supply with a positive output may be used, and vice versa. But such a single polarity DC-ionizer is likely to overcompensate the neutralization and actually charge the material with the opposite polarity. This, however, can be avoided by the use of a double DC-ionizer, Figure 8, where alternate points are connected to a positive and negative voltage source.

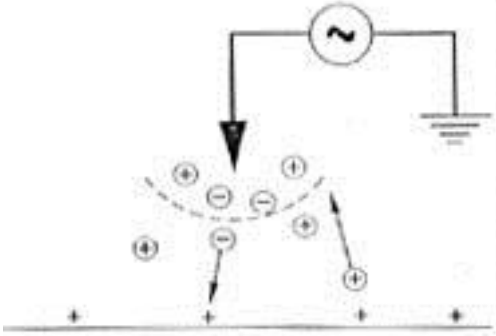

Figure 7. AC-Ionizer

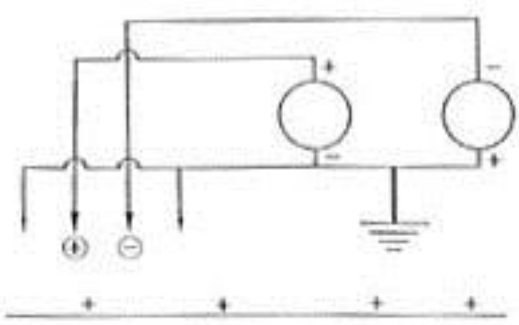

Figure 8. Double DC-Ionizer

RADIOACTIVE IONIZERS

In a radioactive ionizer the radioactive source is placed upon a base material and covered with an extremely thin protective layer, often made of gold. The rod-shaped ionizers are mounted in such a way, that the radiation is directed towards the space immediately in front of the charged material, Figure 9.

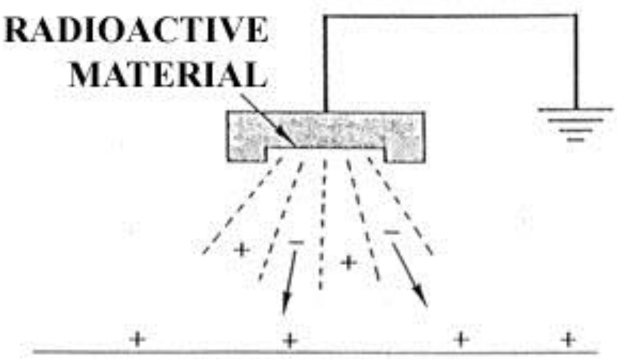

Figure 9. Radioactive ionizer

When one is dealing with relatively low levels of charging, or when the processing speed is slow, radioactive ionizers are very handy. They do not require electrical installations, and they function without electrical discharges, which in case of malfunctioning may cause ignition of inflammable atmospheres.

The limitation to their use lies in the fact, that at high charge levels, one has to use impractical high (radio)activities, or the discharging will take too long.

As far as the radiological hazard is concerned, it is safe to assume, that the direct – external – radiation from the ionizer is insignificant. If, however, the radioactive material, by accident or carelessness, is spread in the environment and for instance by evaporation becomes airborne, it may be inhaled, and the high energetic alpha radiation may eventually cause radiological damage to the respiratory tract, in the worst case initiating the growth of tumours. It should, however, be stressed, that with modern ionizers, the risk with proper handling and care is extremely low.

ION BLOWERS – WHOLE ROOM IONIZATION

The ionizers, described above, are all designed to be mounted immediately in front (or back) of the charged material.

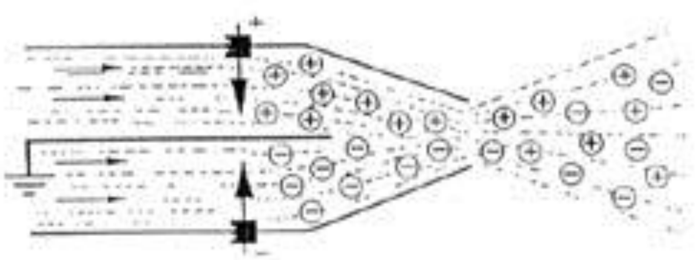

Figure 10. Ion-blower

In many cases, however, this arrangement is not practical or possible, and the ions have to be transported an appreciable distance from their site of production to the place of neutralization, usually aided by an air current.

An ion-blower is essentially an electrical (usually DC-, single or double) or possibly radioactive ionizer encapsuled in a metal house (often forming the counter electrode) with an air orifice.

By blowing air past the region, where ionization takes place, Figure 10, it is possible to create an air jet with a relatively high ion-content. The jet may be directed towards hard-to-reach places or places where work operations prevent the mounting of a direct ionizer. Although it is difficult to maintain a high, even monopolar, ion concentration in a given air volume over long periods or distances because of diffusion, repulsion and combination of the ions, ion-blowers may, especially when dealing with sensitive components, offer the only practical solution.

Some ion-blowers only produce ions of one polarity, but as already mentioned, this may, even when the polarity is correct, not lead to neutralization, but to re-charging of the objects. Hence ion-blowers should, as a rule, deliver a balanced, i.e. neutral, but highly ionized (conducting) air flow.

Over the last few years a variation of the use of (normally) electrical ionizers have gained a growing popularity with the so-called whole room ionization.

A series of point ionizers are mounted in the ceiling of the room and kept at such a voltage with respect to some properly mounted counter electrodes, that corona discharges take place and the ions (of both polarities) are disturbed in the room as a whole, preferably by diffusion or convection, to render air sufficiently conducting for neutralizing charges on work surfaces and elements.

MEASUREMENT OF IONIZATION

A thorough analysis of the ion population in a given atmosphere with respect to concentrations, polarities and mobilities is a very complicated and time consuming affair. And often a detailed knowledge of the ions and their concentrations is of less interest than just knowing what effect the running of an ionizing device has on the decay rate of charges in a given environment. And further, it may not even be practical possible, with any reasonable degree of accuracy, from a knowledge of the atmospheric electric parameters to predict the decay rate of a static charge, because the rate may depend strongly upon where the charge is located especially with respect to grounded surroundings, and upon whether or not the neutralizing charges are moved only because of an attraction from the charge to be neutralized or (partly) by an external electric field or a convectional air flow.

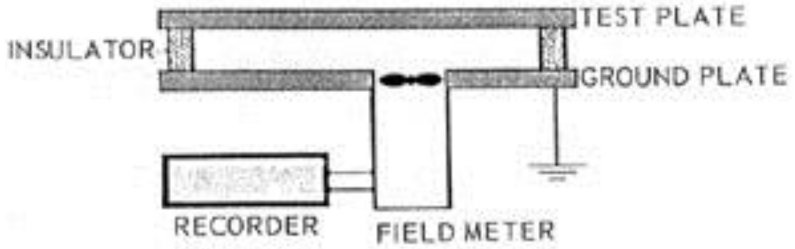

Figure 11. Charged-plate system

In practice, therefore, the charge neutralizing power of a ionizing device or installation is evaluated by the use of a so-called “charged plate”-system, shown principally in Figure 10. The voltage of the charged plate is deduced from the field from the plate measured by the field meter.

The set-up is placed in the environment to be tested, the plate is charged to a given initial voltage, say 1000 or 5000 V, and the decay time to (usually) 10% of the initial voltage is measured. Further equilibrium voltage (off-set voltage) is measured, in order to evaluate the degree of balancing between two polarities. It should be stressed that the decay time measured in this way is different from (longer than) the theoretical neutralization time for free charges deduced from the conductivity of the air. It will also normally be different from the decay time of actual, “practical” charges, because the distribution of the electric flux is unlikely to be the same as with the test set-up.

The charged plate system should therefore be considered as a device to compare the neutralizing ability of different ionizing systems, rather than an instrument to measure the neutralization time of practical charges.

ARE IONS GOOD FOR YOU ?

Atmospheric ions have often been claimed to have physiological, biological or hygienic properties.

One of the most common claims is that air with an excess of small positive ions feels stuffy, while air with an excess of small negative ions feels fresh.

No solid scientific study, however, supports this claim. Quite to the contrary heavy thunder air is rich in small negative ions, fresh mountain air in small positive ones !

Negative ions are often, by manufacturers of monopolar ion generators, claimed to be charged oxygen molecules, while positive ions are said predominantly to attach to dust particles, soot and other unwanted airborne particles.

Thus negative ions should be beneficial to inhale, and positive not. Such a statement is also without any kind of scientific basis.

Buildings with so-called Sick Building Syndrome have been claimed to have a bad ion balance, by which is meant that the air has an excess of small positive ions, which should be caused by the presence of polymeric materials used as floor and wall coverings or by direct production from electronic equipment in the room.

And by the kind of reasoning quoted above this should be bad. The author has seen many recordings of lowered ion concentrations in closed rooms, and always because of high aerosol concentrations, but never, not one case, of dramatic imbalance between the two polarities. Unfortunately most reports on Sick Buildings are too superficial to truly expose this question.

In passing it should also be mentioned, that the production of ions by electrical discharges is always accompanied by the production of ozone, a gas with probably the smallest gap between the lowest concentration that can be detected (by the nose) and the maximum permissible concentration. The ozone characteristics of a given ion source should therefore always be carefully checked.

The whole topic of possible effects of ions (and electrical fields) on human beings has been treated in many papers. One of the best, On the Presence and Generation of AC and DC Electric Fields and Small Ions in Closed Rooms as a Function of Building Materials, Utilization, and Electrical Installation, is written by R. Reiter, in Journal of Geophysical Research, 90, D4, June 30, 1985, pp. 5936-5944).

Dr. Reiter's paper is highly recommended for anybody interested in the topic, and the following quote is to be happily countersigned by any scientist working with atmospheric electricity:

> "Nearly all relevant assertations about harmful or beneficial effects of small ions fail to realize the fundamental elements of atmospheric electricity".

It can, however, by no means be ruled out, that the atmosphere around us, interacts with us by electrical methods, and that the magnitude and distribution of electric charge has an influence on our well being and health.

But such a relation has not yet been shown.

CONCLUSION

It is almost a hundred years since the existence of air ions was established. During the century passed, atmospheric electricity has changed from being a central area of scientific, basic research through a phase of quack metaphysics to become an extremely useful tool in many industries.

Or, rather, all three phases coexist even today.

We can put ions to good use for a lot of purposes, but, in spite of frequent commercial and medical statements, some rather preposterous and ridiculous, we still don't know if ions have any effect at all on human beings, and to be completely truthful, we don't even really know the exact composition of an ordinary air ion.