Balanced Scanning Mobility Analyzer

BSMA3

MANUAL

version 20061116

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Warnings:

- *The instrument contains high voltage circuits. The case of the instrument can be opened only after the power cord has been detached from the instrument for at least 30 s.*
- *The recommendations given in Section 8.1 of the manual should be carefully followed when installing the instrument for routine measurements.*
- *All service operations must be made in accordance with the rules presented in Chapter 8 of the manual.*

1. INTRODUCTION

The BSMA3 is the third and improved model of the Balanced Scanning Mobility Analyzer BSMA (Tammet, 2006), which makes possible simultaneous measuring of positive and negative air ion distribution in the mobility range of 0.032−3.2 $cm^2V^{-1}s^{-1}$ and in the size range of 0.4−7.5 nm. The instrument is designed having in view applications in atmospheric aerosol nucleation research. It provides routine monitoring of cluster ions and charged nanometer particles in atmospheric air. The distinctive properties of BSMA3 are:

- High flow rate about 40 dm^3/s assures representative sampling of the atmospheric air.
- The sheath air is aspirated into the instrument directly from the atmosphere together with the analyzed air and flows during the same air tract.
- Short passage time about 0.1 s and low heating of air less than 0.3 K suppress altering of the ions during the measuring.
- Calibration of the instrument is based on the geometric dimensions, air flow rate, resistances, and voltages.
- Low inlet loss of ions enables reliable estimating and numerical compensation.
- Temperature- and pressure- sensitive calibration coefficients are operatively adjusted during the measurement according to the readings of built-in meteorological sensors.
- The single-channel scanning guarantees that peculiarities in the recorded mobility distribution are not generated by the technical troubles specific for individual channels.
- The size range of 0.4-7.5 nm corresponds to the aerosol nucleation range.
- The methods of calibration are explicitly described in the attached documentation and the source code of the internal data processing is open and available for the user.

The charged nanoparticles are called the intermediate air ions in atmospheric electricity research. According to the traditions of atmospheric electricity a charged cluster or a nanometer particle is called the *air ion* or *ion* in the present manual. Hõrrak et al. (2000) classified the air ions as clusters (diameter up to 1.6 nm), small nanometer particles (diameter 1.6−7.5 nm) and large nanometer particles (diameter 7.5−22 nm). The physical background of the 1.6 nm boundary is the difference between the electron structure of a large molecule and the solid state electron structure of a particle (Tammet, 1995). This empiric limit of 7.5 nm could be related to the size of the growing ion-induced nuclei when the effect of their initial electric charge has died out. This is just the upper boundary of the BSMA3 measuring range.

The clusters and the smallest nanoparticles are the subjects of rapid transformations and their composition can be changed when the air is heated during the passage through the inlet tract and the mobility analyzer. Thus the residence time of the air in the instrument should be short, the heating and drying of the air should be minimized, and the temperature and humidity of the sheath air should be kept the same as in the analyzed air. This was a high-priority requirement considered in the design of the BSMA3. Another high-priority requirement was the suppressing of inlet losses of the highly diffusive clusters and nanoparticles. The estimation of the inlet penetration rate includes a considerable uncertainty and complicates the calibration of the instruments. The relative uncertainty of penetration is suppressed by minimizing the inlet loss of ions.

The problems with distortion of recorded distributions by possible technical troubles in individual mobility channels are avoided in the BSMA3, where all ions are collected onto the same electrode and the mobility is varied by the variation of the analyzer voltage. A voltage change is accompanied with the induced current, which exceeds the ion current many orders of magnitude. In a typical scanning instrument the driving voltage is changed step by step, and the input of the electrometric amplifier is short-circuited during voltage commutation. A known but seldom used alternative is the continuous scanning in the analyzer, where the induced current is compensated by means of a balanced bridge circuit (Erikson, 1921, 1924). This method is applied in the present instrument and the Erikson mobility analyzer can be considered as the first prototype of the BSMA.

2. PRINCIPLES OF MEASUREMENT

2.1. The aspiration condenser and the bridge circuit

The BSMA3 is equipped with two identical plain aspiration condensers. The detailed structure of a condenser is explained in the section 2.7 of the manual. The principle of mobility discrimination is illustrated in Figure 2.1.

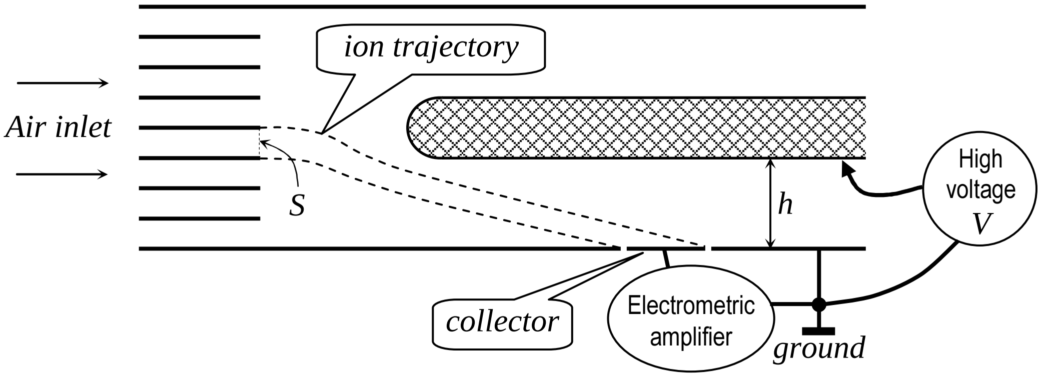


Figure 2.1. Schematic cross-section of 1:4 differential aspiration condenser.

Atmospheric air is passed into the condenser from the left through an electric filter made of parallel plates. The filter has 8 sections, which contain invisible in the figure electrodes. These electrodes allow to close or to open a section for passage of ions. In the normal measuring situation only one section is open for ions and acts as the inlet slit. The ions passing the inlet slit *S* drift with the air from the left to the right and incline down due to the electric field created by the high voltage between the plates. The downward velocity in the plain part of the condenser is $v = ZE$, where E is the electric field and Z is the ion electric mobility. Some ions are deposited onto the collector electrode and the current carried by these ions is measured using an electrometric amplifier. The limiting trajectories of entering ions begin on the edges of the inlet slit. Dimensions of 1:4 aspiration condenser are adjusted so that the ratio of electric fluxes through the collector and through the upper limiting trajectory is exactly 1:4, just like the ratio of air flow rates. Thus both the upper and lower limiting trajectories for ions of certain mobility terminate on the edges of the collector electrode and all ions are captured on the collector. The concentration of ions is calculated according to the measured current. The ions of different mobility are deposited before of after the collector. They are not measured or are measured only partially.

The high voltage between the electrodes of the aspiration condenser must be varied to measure ions of different electric mobility. When the voltage is changed, the electric field induces current though the collector electrode. This current exceeds the ion current in many magnitudes. The induced current can be compensated using the bridge circuit illustrated in Figure 2.2.

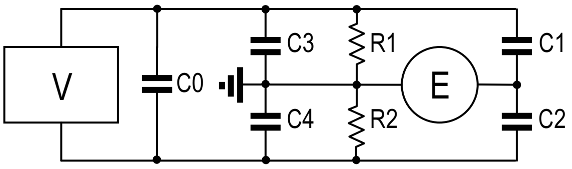


Figure 2.2. The bridge circuit.

The electrometric amplifier E is connected in the diagonal of a bridge formed by two equal resistors R1 and R2, and two equal capacitors C1 and C2. One of these capacitors is formed by the capacitance between the collector electrode and the high voltage repelling electrode of the aspiration condenser. The ion current through this capacitor should be measured. The second capacitor is passive and should not conduct electricity. The bridge is powered by a well-insulated source of high voltage V that can be switched on and off during the measurements. The two equal small capacitances C3 and C4 play a minor role in the measuring process. The mobility scanning is performed by the decay of voltage during the discharging of the large capacitor C0 after disconnecting the power from the high voltage source V. The discharging process is nearly exponential with the time constant of 3.5–4 seconds in the BSMA3. Two decades of mobility are scanned during about 18 seconds. An additional second is added to the period of scanning for the charging of the capacitor C0.

In the Erikson instrument, C1 is the capacitance of the collecting electrode and C2 is the capacitance of a special compensation condenser. These capacitors are exposed to different air conditions that cause fluctuations in the bridge balance. An innovation proposed by Komarov et al. (1961) is used in the BSMA, consisting of two identical aspiration condensers. Both capacitances C1 and C2 are the active capacitances of the collecting electrodes of two identical measuring condensers and are exposed to the similar air flow. The difference is that the air in one capacitor consists of ions, but the air in the second capacitor is fully deionized by means of the controlled electric inlet filter.

2.2. Presentation of the mobility and size distributions

The concentration of ions in a narrow interval of the ion electric mobility dZ around the mobility Z is $dn = f_Z(Z)\ dZ$, where $f_Z(Z)$ is the distribution function of ions according to the mobility. The geometric size of an ion can be described by the ion mass diameter d (Tammet, 1995). The electric mobility depends on the mass diameter as $Z = \mathrm{mob_{air}}\ (d, T, p)$, where $\mathrm{mob_{air}}$ is a specific function, T is air temperature and p is pressure. An approximation of the function $\mathrm{mob_{air}}$ proposed by Tammet (1995) is used in the BSMA3 software. The size distribution of ions is described by the function $f_d\ (d) = dn\ /\ dd$, where dn is the concentration of ions in a narrow interval of the ion size dd. $dZ = (d\ (\mathrm{mob_{air}}\ (d)\ /dd)\ dd$ and

$$f_d\,(d) = \frac{d\ \mathrm{mob_{air}}\,(d)}{dd}\ f_z\,(Z)\,. \tag{2.1}$$

An alternative is the presenting of distributions according to the decimal logarithms of the size and mobility. In this case $dn = f_{\log Z}(Z)\ d(\log Z) = f_{\log d}(d)\ d(\log d)$ and

$$f_{\log d}\,(d) = \frac{d\ \log(\mathrm{mob_{air}}\,(d))}{d(\log d)}\ f_{\log z}\,(Z)\,. \tag{2.2}$$

All equations consisting log d or log Z are conventional abbreviations, because a logarithm can be calculated only from dimensionless quantities. The strict way is to write log $(d\ /\ d_a)$ instead of log d, where d_a is an arbitrary fixed size. However, the differentials are independent of the choice of d_a, and an inconvenient full expression d (log $(d\ /\ d_a)$) is abbreviated as d (log d).

Table 2.1

Units and conversion coefficients

Quantity	SI unit	Practical unit	Ratio
n	$\mathrm{m^{-3}}$	$\mathrm{cm^{-3}}$	10^6
d	m	nm	10^9
Z	$\mathrm{m^{-2}V^{-1}s^{-1}}$	$\mathrm{cm^{-2}V^{-1}s^{-1}}$	10^{-4}
$f_d\ (d)$	$\mathrm{m^{-4}}$	$\mathrm{cm^{-3}nm^{-1}}$	10^{-3}
$f_{\log d}(d)$	$\mathrm{m^{-3}}$	$\mathrm{cm^{-3}}$	10^6
$f_Z(Z)$	$\mathrm{m^{-1}Vs}$	$\mathrm{cm^{-1}Vs}$	10^{10}
$f_{\log Z}(Z)$	$\mathrm{m^{-3}}$	$\mathrm{cm^{-3}}$	10^6

Units of the considered quantities and the conversion coefficient are shown in Table 2.1.

In the BSMA output the distributions are described by means of the fraction concentration tables. A mobility fraction concentration in an interval (Z_1, Z_2) is

$$n(Z_1, Z_2) = \int_{Z_1}^{Z_2} f_z(Z)dZ = \int_{\log Z_1}^{\log Z_2} f_{\log z}(Z)d(\log Z) \tag{2.3}$$

The size fraction concentrations can be expressed in similar way via the functions of the size distribution.

In the BSMA, the "decade to eight" logarithmic fraction scheme is used, where the fraction borders are set according to a geometric sequence with the factor of $10^{1/8} \approx 1.33352$. This scheme is well harmonized with the 1:4 differential aspiration condenser because the ratio of boundary mobilities is very close to the ratio 4:3 of the fluxes in the condenser.

The geometric averages of the borders are considered as the centers of the fractions. The fraction concentration is estimated as the product of the logarithmic distribution function in the center of the fraction and the logarithmic width of the fraction, which is always 1/8. Thus the conversion from the fraction presentation to the distribution function presentation is made according to the approximate equation

$$f_{\log Z}\left(\sqrt{Z_1 Z_2}\right) \approx 8\,n(Z_1, Z_2) \quad \text{and} \quad f_{\log d}\left(\sqrt{d_1 d_2}\right) \approx 8\,n(d_1, d_2) \tag{2.4}$$

The BSMA software is designed with the aim of measuring concentrations of 10 size fractions, the borders and centers of which are shown in Table 2.2.

Table 2.2

Size fractions and corresponding electric mobilities in typical and extreme conditions

d : nm		Z : cm^{2}V^{-1}s^{-1}	Z : cm^{2}V^{-1}s^{-1}	Z : cm^{2}V^{-1}s^{-1}
border	center	–20 C & 1050 mb	10 C & 1000 mb	40 C & 950 mb
0.422		2.3646	2.7158	3.0916
	0.487	2.0676	2.3590	2.6706
0.562		1.8005	2.0429	2.3022
	0.649	1.5573	1.7593	1.9756
0.750		1.3356	1.5038	1.6840
	0.866	1.1347	1.2743	1.4239
1.000		0.9545	1.0697	1.1932
	1.155	0.7937	0.8865	0.9847
1.334		0.6432	0.7110	0.7814
	1.540	0.4960	0.5426	0.5920
1.778		0.3717	0.4071	0.4456
	2.054	0.2816	0.3104	0.3418
2.371		0.2175	0.2409	0.2662
	2.738	0.1698	0.1885	0.2087
3.162		0.1330	0.1477	0.1636
	3.652	0.1040	0.1155	0.1279
4.217		0.0811	0.0900	0.0997
	4.870	0.0630	0.0699	0.0773
5.623		0.0488	0.0541	0.0598
	6.494	0.0376	0.0417	0.0461
7.499		0.0290	0.0321	0.0354

The boundary electric mobilities in Table 2.2 are variable and they are not arranged according to the "decade to eight" scheme. The BSMA direct output is the electric mobility distribution. The size fraction concentrations are calculated afterwards. The adjusting of the primary mobility fraction scheme according to air temperature and pressure is not reasonable. Thus a fixed primary mobility fraction scheme is used, which is harmonized with the instrument hardware but not harmonized with the size fraction scheme. 16 fractions are required to cover all mobilities listed in Table 2.2. The boundaries of the mobility fractions are independently arranged according to the "decade to eight" scheme. The boundaries and centers and expressed in the practical units cm^{2}V^{-1}s^{-1} below:

0.0316 (0.0365) **0.0422** (0.0487) **0.0562** (0.0649) **0.0750** (0.0866)
0.1000 (0.1155) **0.1334** (0.1540) **0.1778** (0.2054) **0.2371** (0.2738)
0.3162 (0.3652) **0.4217** (0.4870) **0.5623** (0.6494) **0.7499** (0.8660)
1.000 (1.155) **1.334** (1.540) **1.778** (2.054) **2.371** (2.738) **3.162**

The fraction schemes of the mobility distribution and the size distribution are not agreed with each other. The size distribution should be calculated according to the mobility distribution according to a complicated algorithm, which takes into the account the air temperature and pressure in the instrument. The BSMA3 contains the temperature and pressure sensors, and the calculations are made by the control program simultaneously with the measuring process.

2.3. Diffusionless transfer function

The thermal and turbulent diffusion and the divergent electric field of possible space charge are neglected in the diffusionless model. Divergences of both the air velocity and the electric field are zero, and it follows the ion concentration is conserved along an ion trajectory independent of air flow distribution and the configuration of the electric field (Tammet, 1970). The number flux of ions of the mobility Z through any imaginary surface where the concentration of ions n is constant, is $(Q + ZN)\,n$, where Q is the air flow through the surface and N is the flux of the electric field through the surface. If the imaginary surface is composed of the trajectories of ions of a certain mobility Z, then the flux of ions through this surface is zero because the ions are moving along the surface and do not cross it. Thus $Q + ZN = 0$ and the absolute value of the mobility, the air flow rate and the flux of electric field corresponding to a surface composed of trajectories of ions satisfy the equation

$$Z = Q / N \tag{2.5}$$

independent of the profile of air velocity and the configuration of the nondivergent electric field.

Two diffusionless ion trajectories in the mobility analyzer are shown with dotted lines in Figure 2.1. The ion mobility corresponding to the upper trajectory is denoted by Z_1. We see only a cross-section of the aspiration condenser in Figure 2.1. Actually, the dotted line corresponds to a surface made of parallel trajectories located in different cross-sections of the condenser. The air flow rate through the upper surface is $4Q_\Delta$, where Q_Δ is the air flow through one section of the inlet filter. The flux of the electric field N_1 is determined by the electric charges on the surrounding metal plates on both sides of the considered trajectory independent of the configuration of the trajectory between its fixed beginning and end. If this flux is known, the mobility is calculated as

$$Z_1 = 4Q_\Delta \; / \; N_1 \, . \tag{2.6}$$

The lower trajectory in Figure 2.1 begins just between the third and fourth sections of the inlet filter and ends on the front edge of the collector plate. The air flow rate through the surface of ion trajectories is $3Q_\Delta$, and the mobility corresponding to the lower trajectory Z_2 is

$$Z_2 = 3Q_\Delta \; / \; N_2 \, , \tag{2.7}$$

where N_2 is the corresponding flux of the electric field.

The electric field in the aspiration condenser of the BSMA was computed by solving numerically the two-dimensional Laplace equation on the grid with 0.1 mm mesh and considering all details of the condenser configuration including the finite thickness of the filter plates. The position of the collector plate in the condenser was adjusted in such a way that $N_1 / N_2 = 4 / 3$. As a result, we have a common central mobility of the analyzer

$$Z_o = Z_1 = Z_2 \, . \tag{2.8}$$

All ions of central mobility entering the fourth section of the inlet filter, which acts as the inlet slit, are deposited on the collector in the diffusionless model. The geometry of the analyzer and the air flow rate are fixed and the central mobility can be varied by changing the voltage V on the ion repelling plate of the analyzer. Equations (2.6) and (2.7) show that the central mobility is inversely proportional to the voltage:

$$Z_o = c_z / V, \tag{2.9}$$

where c_z is a calibration coefficient of the analyzer. The calibration constant can be determined according to the equations above after measuring the air flow rate and calculating the electric field in the condenser. The air flow rate in the BSMA3 was measured using a rotary gas flow meter and the uncertainty of the coefficient c_z does not exceed few per cent. Details of the calibration of the BSMA3 are discussed later in Chapter 5 of the manual.

In the standard regime the three lower sections of the inlet filter are penetrable for air flow but electrically locked for ions. The concentration of ions in a narrow mobility interval dZ around Z_o is $dn = f(Z_o)\, dZ$, where $f(Z)$ is the distribution function of ions according to the mobility. The ions are expected to carry a single elementary charge e, and the electric current transmitted to the collector by ions around the central mobility entering the fourth section of the inlet filter is $eQ_\Delta f(Z_o)dZ$. If the mobility deviates from the central mobility, then some ions will be deposited before the collector or behind the collector. The electric current is a linear function of the mobility until all ions will be deposited away of the collector. This happens when $Z < 3Z_o / 4$ or $Z > 4Z_o / 3$. Thus the current of collected ions in a narrow mobility interval around an arbitrary mobility is

$$dI = eQ_\Delta\, \gamma_{3/4}\,(Z / Z_o)\, f\,(Z)dZ\ , \tag{2.10}$$

where $\gamma_{3/4}$ is the triangular function illustrated in Figure 2.3.

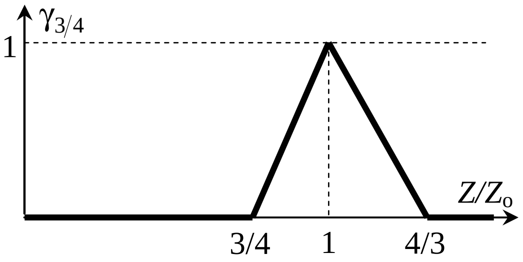


Figure 2.3. Illustration of the function $\gamma_{3/4}(Z/Z_o)$.

The formal expression of this function is

$$\gamma_{3/4}(x) = \begin{cases} \text{if } \ x < \dfrac{3}{4} \ \text{ then } \ 0 \\ \text{if } \ \dfrac{3}{4} \le x \le 1 \ \text{ then } \ 4x - 3 \\ \text{if } \ 1 \le x \le \dfrac{4}{3} \ \text{ then } \ 4 - 3x \\ \text{if } \ \dfrac{3}{4} < x \ \text{ then } \ 0 \end{cases} . \tag{2.11}$$

The integral over the $\gamma_{3/4}$ function is 7 / 24. A random variable, which is characterized with the $\gamma_{3/4}$ distribution, has the mean value of 1.02778 and the standard deviation of 0.11928.

The current carried to the collector by all ions is expressed as an integral over all values of the mobility

$$I(Z_\circ) = \int G(Z_\circ, Z)\, f\,(Z)dZ\ , \tag{2.12}$$

where

$$G(Z_\circ, Z) = eQ_\Delta \gamma_{3/4}\left(\frac{Z}{Z_\circ}\right) \tag{2.13}$$

is called the diffusionless transfer function or the apparatus function of the instrument.

In case of monomobile ions of mobility Z_x the distribution function can be written using the Dirac delta function as $f(Z) = n\delta(Z - Z_x)$. Equation (2.12) results then in $I(Z_o) = nG(Z_o, Z_x)$. Thus the transfer function is interpreted as the response of the instrument to the monomobile ions of the unit concentration.

2.4. Estimating the mobility distribution

The inversion of the integral transform (2.12) is problematic at atmospheric measurements because the inversion drastically reduces the signal to noise ratio, which is usually low and does not allow any decrease in data processing. Thus the width of the transfer function limits the real mobility resolution of the instrument with the ratio of distinguishable mobilities 4/3 and allows to resolve up to 8 fractions per decade in the logarithmic scale because $(4/3)^8 = 9.98872 \approx 10$.

The transfer function (2.13) differs from zero only in a relatively narrow interval

$$\frac{3}{4}Z_\circ < Z^* < \frac{4}{3}Z_\circ . \tag{2.14}$$

The average value of $f(Z)$ can be estimated according to the first mean value theorem for integration stating that this interval contains a value Z^*, which assures exactly

$$I(Z_\circ) = f(Z^*)\int G(Z_\circ, Z)dZ . \tag{2.15}$$

The integral of the transfer function is

$$\int G(Z_\circ, Z)dZ = \frac{7}{24}eQ_\Delta Z_\circ \tag{2.16}$$

and the distribution function has a value

$$f(Z^*) = \frac{24}{7}\frac{I(Z_\circ)}{eQ_\Delta Z_\circ} \tag{2.17}$$

somewhere in the mobility interval (2.14). In case of a locally smooth distribution, the mobility Z^* is located close to the central mobility Z_o. Thus the distribution function can be estimated according to the modified equation

$$f(Z_o) \approx \frac{24}{7}\frac{I(Z_\circ)}{eQ_\Delta Z_\circ} . \tag{2.18}$$

The estimate (2.18) is exact on the concentration scale and its uncertainty on the mobility scale is limited by interval (2.14). An alternative interpretation of the estimate (2.18) is a smoothed image of the real distribution where the window of the smoothing filter is the normalized triangular function of the same shape as the function $\gamma_{3/4}$. The relative width of this smoothing window can be roughly characterized by the standard deviation of the $\gamma_{3/4}$-distribution function, which is about 12%.

A fraction concentration of ions in an interval (a, b) can be presented via the average value of the distribution function in this interval

$$n_{(a,b)} = (b-a)\overline{f(Z)} . \tag{2.19}$$

If the distribution is locally smooth then the average value is close to the value of the function in the center of the interval. In the "decade to eight" scheme, the proper fraction boundaries are $a = 10^{-1/16} Z_o$ and $b = 10^{1/16} Z_o$. In this case $b - a = (10^{1/16} - 10^{-1/16})Z_o$ and the fraction concentration is estimated as

$$n_{(a,b)} \approx (10^{1/16} - 10^{-1/16})\frac{24}{7}\frac{I(Z_\circ)}{e\Phi_\Delta} \approx 0.99\frac{I(Z_\circ)}{e\Phi_\Delta} . \qquad (2.20)$$

The coefficient 0.99 is close to 1 and we see again that the "decade to eight" scheme is well harmonized with the 1:4 structure of the aspiration condenser.

2.5. Broadening the transfer function at the continuous scanning

In the BSMA the voltage of the aspiration condenser changes smoothly and the mobility range of one fraction is continuously passed during about one second. 10 measurements of the ion current are made in the course of one second. The transfer function (2.13) is immediately valid for only one measurement made in the center of the fraction. The measurements of the ion current consist of instrumental noise and this noise can be suppressed by averaging of the repeated measurements. Thus the ion current in the BSMA is actually calculated according to the average value of about 10 measurements made during the passage of the voltage through the fraction voltage range. The averaging flattens the measured mobility distribution and can be interpreted as the broadening of the transfer function.

The averaging over a mobility fraction during the continuous scanning of mobility is equivalent to the smoothing filter with a rectangular window with borders of $10^{-1/16}$ and $10^{1/16}$. The relative standard deviation of this window of 8.3% is less than the 12 % standard deviation of the $\gamma_{3/4}$-window of the triangle transfer function, and the composite standard deviation of the smoothing of the mobility distribution is 14.6 %.

The BSMA actual measurements are the fraction concentrations and the indirect effect of broadening can be learned by calculating the fraction distributions corresponding to the narrow distributions of the ion mobility. The calculations were made by means of a computer program, considering the triangular transfer function and the ten-measurements averaging the electrometer signal over the fraction mobility range. Some results are presented in Table 2.3.

Table 2.3

Distribution of the simulated fraction signals

Actual mobility distribution	Simulated signal, fraction 1	Simulated signal, fraction 2	Simulated signal, fraction 3
Monomobile ions in the center of the fraction 2	12%	75%	13%
Monomobile ions between the fractions 2 and 3	0%	48%	52%
Uniform distribution in limits of the fraction 2	17%	66%	17%

2.6. Diffusion broadening of the transfer function

The diffusion of ions leads to two unwanted effects: broadening of the transfer function and loss of ions in the inlet tract of air.

Broadening of the transfer function has been thoroughly analyzed by Salm (2000). The Brownian walk and turbulent fluctuations make the ion trajectories rugged and randomly fluctuating. As a result, the ion of the central mobility, which has started from the edge of an inlet filter plate, does not hit the edge of the collector plate. The mobility, still calculated according to the coordinate of ion deposition is called the apparent mobility of the ion in the instrument. The distribution of ions according to the apparent mobility $f^*(Z')$ can be expressed as a linear integral transform of the real distribution:

$$f^*(Z') = \int W(Z', Z) f(Z) dZ \qquad (2.21)$$

where $W(Z',Z)\,dZ$ is the probability of the event that an air ion of real mobility Z possesses the apparent mobility in the interval dZ around Z'. In the presence of the diffusion the function $f(Z)$ in Equation (2.12) should be replaced by the function of apparent distribution $f^{*}(Z)$. While the diffusion is weak, the kernel $W(Z',Z)$ of the transform (2.21) is similar to the Gaussian smoothing window (Salm, 2000). Thus an immediate measuring result can be interpreted as a triple-smoothed image of the real distribution: at first according to the triangular window of well-known shape and width, next by the integration during the continuous scanning, and at last, according to a nearly Gaussian window of width, which can be estimated in rough approximation by means of test experiments.

The diffusion smoothing conserves the total ion concentration and can slightly shift the mean mobility. The mobility shift is an effect of the second order of magnitude and can be ignored in the BSMA3 because this instrument has a low mobility resolution due to the wide inlet slit and collector electrode. The relative spread of mobilities due to the Brownian diffusion estimated according to Tammet (1970) is less than 3% and can be neglected during data interpretation. The spread of the mobilities due to the turbulent diffusion is bigger and can be compared with the spread due to the width of the diffusionless transfer function.

2.7. Construction of the aspiration condenser

The dimensions of the aspiration condenser are shown in Figure 2.4.

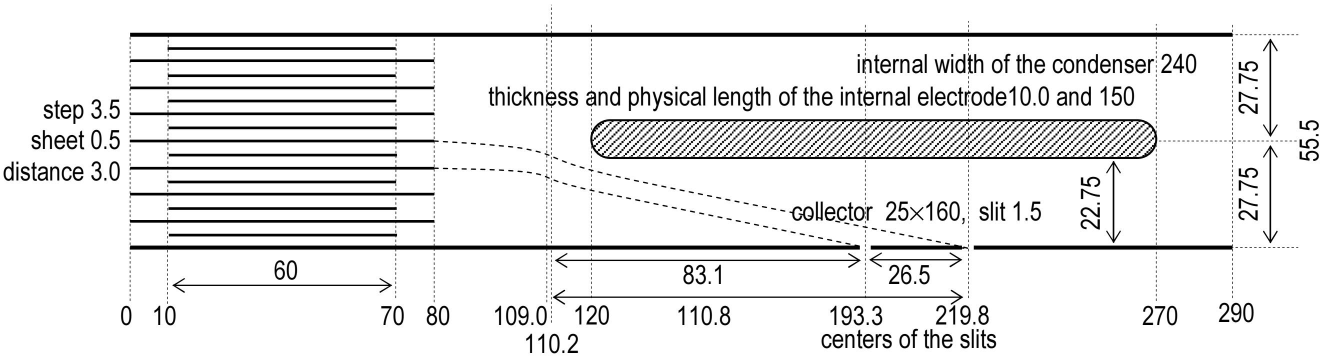


Figure 2.4. Schematic cross-section of an aspiration condenser of the BSMA3.

Two aspiration condensers of the instrument are mirror images of each other. Figure 2.4 corresponds to the view of the left condenser from below and the view of the right condenser from above. The overall length of a condenser including the inlet filter is 290 mm. Coordinates are measured from the left inlet end of the condenser. The width of the condenser in the direction perpendicular to the depicted cross-section is 240 mm. A voltage up to 3 kV is applied to the central repelling electrode, which is fastened to polycarbonate insulators, see Figure 2.5.

The ions are collected on a 25 mm long and 160 mm wide collector, which is fastened using slightly heated insulators made of polyether imide. Atmospheric air is passed into the condenser in Figure 2.4 from the left through an electric filter made of parallel plates. The filter allows controlling the inlet of ions and suppresses the carried on turbulence, which could harm the mobility resolution at a windy weather. The air flow rate in one condenser is about 19.5 l/s. Corresponding velocity of the air in the filter is 1.7 m/s and between mobility analyzer electrodes 1.8 m/s. The internal stability of air flow and transfer from the laminar regime to the turbulent regime in a long flat channel depends on the Reynolds number related to the distance between the plates h: $\mathrm{Re} = uh / \nu$, where u is the average air velocity and ν is the kinematic viscosity of the air. The turbulence can develop in the channel when the Reynolds number exceeds 1200. The Reynolds number is about 340 in the filter of the BSMA3 and the filter well suppresses the carried-on turbulence of the outside air. The Reynolds number of about 2700 between the mobility analyzer electrodes exceeds the critical limit. Turbulence of the air broadens the transfer function and decreases the resolving power of the instrument. However, a high Reynolds number itself does not follow a strong turbulence in a short channel because the turbulence cannot develop instantly (Tammet, 1970; Rosell-Llompart et al., 1996). The short classification region in the BSMA3 avoids strong turbulence and suppresses the effect of turbulence on the transfer function. However, a slight broadening of the measured mobility distribution is evident. In the test experiments, this extra broadening did not exceed the width of the geometric transfer function. In atmospheric measurements of low concentration ions, the real resolving power is additionally limited due to the measurement noise. Thus the turbulent broadening of the transfer function is not the main factor of the mobility resolution when using the BSMA in the research of ion-induced nucleation in the atmosphere.

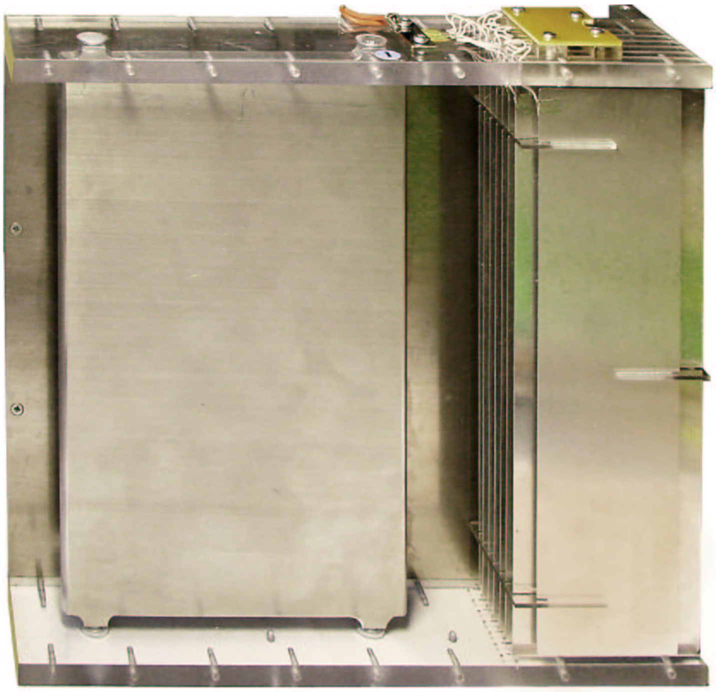


Figure 2.5. The aspiration condenser of the BSMA3 without one side panel.

The dimensions of the condenser are chosen in such a way that the ratio of electric fluxes through the surfaces of critical trajectories (dashed lines in Figure 2.4) is exactly 4/3. The electric flux in an ideal parallel plate capacitor is $N = WLV / h$, where W is the width, L is the length of the capacitor, h is the distance between the plates and V is the voltage. Air flow rate over the collector of the aspiration condenser is $Q = Whu$, where u is the average air velocity between plates. Equation of critical mobility (2.6) can be rewritten as

$$Z = \frac{Q}{N} = \frac{h^2 u}{LV}. \tag{2.22}$$

Equation (2.22) is written for an ideal flat capacitor. The electric field in the real aspiration condenser is distorted near the beginning of the internal repelling electrode. However, if the quantity L is interpreted as the electrostatic effective length defined as

$$L = \frac{Nh}{VW}, \tag{2.23}$$

then Equation (2.22) is valid in case of the aspiration condenser of the BSMA3 as well. The effective length cannot be directly measured using geometric instruments. It can be determined when measuring the electric capacitance or solving the Laplace equation. The effective lengths of the BSMA3 aspiration condenser are determined by means of the second method. The lengths 83.1 mm and 110.8 mm corresponding to the two critical trajectories are shown in Figure 2.4. The effective length can be interpreted as the length of a mobility-equivalent ideal plain capacitor. A point in distance *L* from the end of the ion trajectory is the virtual beginning of the equivalent ideal capacitor. The beginnings are slightly different for different trajectories, because a part of the electric flux is directed from the internal electrode to the inlet filter.

The ions are collected on a 25 mm long and 160 mm wide collector, which is fastened using heated insulators made of polyether imide. The upper half of the aspiration condenser is not used for ion collection; it is necessary for the symmetry of the analyzer and helps to provide good insulation of the repelling electrode. For the sake of symmetry both the filter sections number 4 and 5 are used as the ion inlet gates. The symmetry makes it possible to use relatively simple exact methods for calculating the calibration coefficients of the instrument.

The side panels of the condensers and all long electrodes of the filters are connected to the ground. The outer short electrodes of the filters are connected to the constant voltage of 500 V and the corresponding sections are permanently locked for the passage of ions by the electric field. This creates the ion free sheath air required in the second order differential method. The peculiarity of such provision of the sheath air is that the air temperature and humidity remain undisturbed. The mobility of the ions that could pass the locked sections is less than 0.005 $cm^2V^{-1}s^{-1}$. Such ions could reach the collector only when passing through the closest to the collector section of the filter. The voltage on the filter has an opposite polarity when compared with the voltage on the central repelling electrode of the analyzer. As a result, the low mobility ions are shifted off the collector already in the filter, and their effect is suppressed. There may remain a minor amount of low mobility ions passing the sheath air sections of the filter and reaching the collector due the turbulent pulsations. A systematic effect of these ions in measurements is eliminated by the modulation principle of measurement as described in chapter 4 of the manual.

3. INLET LOSSES OF IONS

3.1. Estimating the diffusion losses in a flat slit of the inlet filter

In case of the ion and nanometer aerosol deposition, the preconditions required for the full analogy of heat and mass transfer (see Kays et al. 2005, chapter 18) are well satisfied and the equations of the heat transfer from the surface of constant temperature can be used replacing the Nusselt number Nu with the Sherwood number Sh and the Prandtl number Pr with the Schmidt number Sc (Incropera and Dewitt, 2002).

The adsorption of ions on a flat plate is described by the deposition velocity u_{dep} defined as the ratio of the ion deposition flux density to the ion concentration, which is measured far from the adsorbing surface. The deposition flux of ions onto both plates of a flat channel is $q_{dep} = 2WLnu_{mdep}$, where W is the width and L is the length of the channel, n is the undisturbed concentration of ions and u_{mdep} is the mean deposition velocity. The inlet flux of ions is $q_{in} = Whnu_{flow}$, where h is the distance between the plates and u_{flow} is the mean inlet velocity. Thus the relative adsorption in a flat filter channel is

$$A_{flat} = \frac{q_{dep}}{q_{in}} = \frac{2Lu_{mdep}}{hu_{flow}}. \qquad (3.1)$$

The deposition velocity is an argument of the Sherwood number, which can be evaluated using equations of the theory of the mass or concentration transfer. The mean deposition velocity is

$$u_{mdep} = (D/L)Sh_{mL}\,, \qquad (3.2)$$

where Sh_{mL} is the mean Sherwood number related to the length L and D is the ion diffusion coefficient. The substitution results in

$$A_{flat} = \frac{2D\,Sh_{mL}}{hu_{flow}}. \qquad (3.3)$$

The air enters into a channel as a plug flow and the boundary layers on the plates will develop along the channel. The displacement thickness of the boundary layer is estimated (see Incropera and Dewitt, 2002) as

$$\delta_{disp} = 1.72\sqrt{\frac{\nu L}{u_{flow}}}\,, \qquad (3.4)$$

where ν is the kinematic viscosity of air. A numeric calculation shows that the displacement thickness in the BSMA3 inlet filter is much less than the distance between the plates h. Thus a result obtained for the boundary layer over a flat plate (see Incropera and Dewitt, 2002) can be adopted in our problem:

$$Sh_{mL} = 0.664 Re_L^{1/2} Sc^{1/3}. \qquad (3.5)$$

The equation above takes into consideration the entrance profile for the ion concentration as well as for the air flow. The Reynolds number is related to the same length L and velocity u_{flow} as the Sherwood number

$$Re = \frac{u_{flow}L}{\nu}. \qquad (3.6)$$

The Schmidt number is the ratio of the kinematic viscosity of the air to the diffusion coefficient of ions:

$$\mathrm{Sc} = \frac{\nu}{D}. \qquad (3.7)$$

Equation (3.5) is valid when Sc > 0.6 (Incropera and Dewitt, 2002). The Schmidt number has the lowest value of about 3 in the case of cluster ions. Thus the concentration boundary layer is always thinner than the velocity boundary layer, and Equation (3.5) can be used for the evaluation of the ion deposition without restrictions until the boundary layer remains thin enough: $\delta_{disp} << h$.

The diffusion coefficient of single charged ions of the electric mobility Z is

$$D = \frac{kTZ}{e}, \tag{3.8}$$

where k is the Boltzmann constant, T is the absolute temperature, and e is the elementary charge. The composite equation for the relative adsorption is a result of several simple substitutions:

$$A_{flat} = 1.33 L^{1/2} h^{-1} u_{flow}^{-1/2} \nu^{-1/6} D^{2/3} = 1.33 (k/e)^{2/3} L^{1/2} h^{-1} u_{flow}^{-1/2} \nu^{-1/6} T^{2/3} Z^{2/3}, \tag{3.9}$$

3.2. Estimating the diffusion losses on the inlet grid

If the grid is made of thin wires then the loss of ions can be estimated replacing the grid with a set of individual cylindrical wires. Adsorption on a wire can be calculated according to the Churchill-Bernstein equation (see Tammet and Kulmala, 2007). The replacement of the BSMA3 grid with a set of individual wires is a very rough approximation. Thus the reliable theoretical result is that the adsorption can be presented as

$$A_{grid} = const \times u_{flow}^{-1/2} \nu^{-1/6} T^{2/3} Z^{2/3}, \tag{3.10}$$

where the coefficient of proportionality *const* depends on the dimensions of the grid. The coefficient is rather to be determined experimentally comparing the measurements made with and without the inlet grid. The experimental procedure is described in Chapter 5 of the manual.

3.3. Estimating of the edge effect

The electric field in the measurement condenser deposits some amount of ions onto the rear edges of the filter plates. The loss of ions due to the edge effect rapidly decreases with the increase in the distance between the filter and inner electrode of the condenser. Unfortunately, this is accompanied with an increase in the turbulent and Brownian mixing of ions between the ion entrance slit and the analyzer part of the condenser, followed by a decrease in the mobility resolution of the instrument. The BSMA3 is designed considering a compromise between a low inlet loss and good resolving power.

If the ion diffusion adsorption is neglected, then the edge loss of ions can be estimated theoretically in the following way.

The flux of ions between the filter plates approaching the entrance slit S (see Figure 2.1) is $I_o = neQ_{uS}$, where Q_{uS} is the air flow through the slit S. The electric field is depositing a part of ions on the rear edges of filter plates. The flux of lost ions is $I_F = neZQ_{ES}$, where Z is the mobility of ions and Q_{ES} is the flux of electric field through the surface S shown in Figure 2.1. The relative loss of ions is $A_{edge} = I_F / I_o = ZQ_{ES} / Q_{uS}$. The mobility of ions drifting along the trajectories between the edges of entrance slit and the edges of collector electrode equals to the ratio of air flow and electric flux though the surface composed of trajectories (Tammet, 1970). The fluxes of air and electric field through the upper trajectory surface are $Q_{u4} = 4Q_{uS}$ and Q_{E4}. Thus $Z = 4Q_{uS} / Q_{E4}$ and

$$A_{edge} = 4Q_{ES} / Q_{E4}. \tag{3.11}$$

The ratio of electric fluxes does not depend on the ion mobility and air flow. It can be numerically calculated solving the two-dimensional Laplace equation. Thus the relative edge effect loss of ions is a fixed number, which depends only on the geometry of the condenser. The numerical solution of the Laplace equation for the BSMA3 aspiration condenser results in

$$A_{edge} = 0.043.$$

3.4. Complex inlet loss of ions

There are four different inlet sinks of ions: diffusion adsorption on the inlet grid, diffusion adsorption on short internal plates of the inlet filter, diffusion adsorption on long external plates of the inlet filter, and edge effect on the rear edges of the long external plates of the inlet filter. The most complicated problem is the combination of the two last sinks, because they are theoretically estimated only when neglecting one of the sinks. These sinks should not be straightforwardly summarized, because the edge effect deposits ions only from the near-plate layer of air, where ion concentration is already suppressed by the diffusion adsorption. A correct way of combination is not known. Thus a simplest formal approximation is used in the BSMA data processing model:

$$A_{external\ plates} = \sqrt{A_{Dext}^2 + A_{edge}^2}\ . \tag{3.12}$$

where A_{Dext} is the diffusion loss on the external plates, which can be calculated according to Equation (3.9). The relative ion loss on the short internal plates A_{Dint} of the filter is calculated in the same way as diffusion loss on the external plates, only difference is the different length. If the lenghts of plates are L_{int} and L_{ext}, then $A_{D\mathrm{int}} = A_{Dext}\sqrt{L_{\mathrm{int}} / L_{ext}}$. Loss of ions on the inlet grid cannot be straightforwardly added to the loss in the filter. Instead of summarizing the losses the penetration coefficients $P = 1 - A$ should be multiplied. Finally, the complex penetration coefficient of the inlet is calculated in the following way:

$$P_{inlet} = 1 - A_{inlet} = \left(1 - A_{grid}\right)\left(1 - A_{Dext}\sqrt{L_{\mathrm{int}} / L_{ext}} - \sqrt{A_{Dext}^2 + A_{edge}^2}\right). \tag{3.13}$$

The term A_{Dext} in Equation (3.13) depends on the ion mobility, air flow velocity, air temperature, and air kinematic viscosity. The dependence of diffusion adsorption on air viscosity is weak in Equation (3.9) and the kinematic viscosity can be estimated according to a simplest approximation

$$\nu \approx (T / 273.15\mathrm{K})^2 (1013\mathrm{mb} / p) \times 13.2\mu\mathrm{Pa\ s}\ , \tag{3.14}$$

which includes the air pressure as an additional parameter.

3.5. Compensation of inlet losses in the BSMA3

Above considerations suggest a compensation of inlet losses in the function of mobility distribution $f(Z)$ by dividing the immediately measured value to the inlet penetration coefficient

$$f(Z) = \frac{f_{uncorrected}(Z)}{\left(1 - A_{grid}(p,T,Q,Z)\right)\left(1 - A_{Dext}(p,T,Q,Z)\sqrt{\dfrac{L_{int}}{L_{ext}}} - \sqrt{A_{Dext}^2(p,T,Q,Z) + A_{edge}^2}\right)}\ . \tag{3.15}$$

In practice, the factors that depend only on the instrument geometry can be precalculated and only the variable part of equations should be computed during the measurements.

In the BSMA3 the air flow rate Q is calculated according to the sensor readings. Air velocity u is proportional to Q and thus the relative diffusion adsorption is proportional to the term $Q^{-1/2}\nu^{-1/6}T^{2/3}Z^{2/3}$. The kinematic viscosity is proportional to the term T^2p^{-1} and the relative diffusion adsorption is proportional to the term $Q^{-1/2}p^{1/6}T^{1/3}Z^{2/3}$. Now A_{grid} and A_{Dext} can be written in the following way

$$\left.\begin{aligned} A_{grid}(p,T,Q,Z) &= c_{grid}\left(\frac{p}{1013\,\mathrm{mb}}\right)^{1/6}\left(\frac{T}{273\,\mathrm{K}}\right)^{1/3}\left(\frac{Q_{\mathrm{o}}}{Q}\right)^{1/2}\left(\frac{Z}{1\,\mathrm{cm}^2\mathrm{V}^{-1}\mathrm{s}^{-1}}\right)^{2/3} \\ A_{Dext}(p,T,Q,Z) &= c_{filter}\left(\frac{p}{1013\,\mathrm{mb}}\right)^{1/6}\left(\frac{T}{273\,\mathrm{K}}\right)^{1/3}\left(\frac{Q_{\mathrm{o}}}{Q}\right)^{1/2}\left(\frac{Z}{1\,\mathrm{cm}^2\mathrm{V}^{-1}\mathrm{s}^{-1}}\right)^{2/3} \end{aligned}\right\}, \tag{3.16}$$

where Q_o is the definite conventional value of flow rate, c_{grid} is the subject of experimental determination and c_{filter} is calculated according to Equation (3.9) as the value of A_{Dext} for the mobility of 1 cm^{2}V^{-1}s^{-1} at standard conditions $Q = Q_o$, p = 1013 mb, and T = 0°C. There are no formal rules how to choose the conventional value Q_o, the most convenient choice is the average real value in typical conditions.

The penetration of particles though inlet screen and filter of the BSMA3 in standard conditions of the air is shown in Figure 3.1.

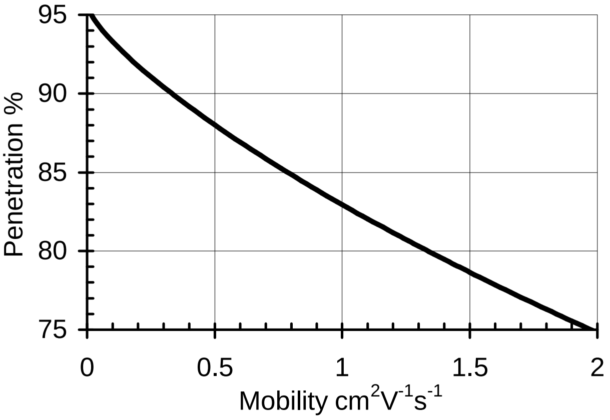


Figure 3.1. Penetration of ions and particles through the inlet screen and filter of the BSMA3 at standard pressure.

4. THE CONTROL PROGRAM BSMA3A

4.1. Outline of the program

The technical diagnostics of the BSMA3 and regular measurements are controlled by a computer running the control program BSMA3A. The program file BSMA3A.EXE is compiled from the source BSMA3A.PAS using TURBO PASCAL and it works under MS-DOS. The listing of the source code is presented in a separate document. It is expected below that the active folder of the computer is the BSMA home folder, which contains the file BSMA3A.EXE.

When BSMA3A is launched, it looks in the home folder for two separate calibration files BSMA3A.INI and BSMA3.DLF. If the instrument calibration file BSMA3A.INI is not available, then the program delivers a corresponding message and stops. If the timing calibration file BSMA3.DLF is not available, then the program launches a procedure of calibration of the computer and ADC timing and saves the calibration file for later usage. The full calibration requires about 10 minutes. If the file BSMA3.DLF is found, then the program checks the correctness of timing calibration during a two-minute procedure. This procedure can be skipped by pressing a key on the computer keyboard. If the check procedure is not skipped and the computer discovers an inaccuracy of the saved calibration, then the full 10-minute procedure is performed and a new calibration file is saved. The history of calibrations is saved in the logfile TIMING.LOG.

After successful reading of calibration files the control program displays the start menu, shown in Figure 6.1. The instruction of practical usage of the control program during routine measurements is presented in Chapter 6 and the test operations are described in Chapter 8 of the manual. The present chapter consists of the explanation of the principles of the measuring algorithm. The details of the algorithm are available in the source code of the control program.

4.2. Calibration data

There are two kinds of the calibration constants: internal and external. Internal constants are expected to be stable and they are included into the program source code. The internal constants can be changed only by editing and recompiling the source. An excerpt from the program BSMA3A (version 20061115) including the calibration constants is:

```
asymmetry = 1; {divider for negative and multiplier for positive ion n}
voltagefactor = 222; {at standardflowrate and balanceresistor = 0}
concentrationfactor = 222; {at standardflowrate, electrometergain = 1,
                            and neglecting inlet losses}
grid_adsorptioncoefficient      = 0.06;  {for Z = 1 cm2V-1cm-1, 0 C, 1013 mb}
longplate_adsorptioncoefficient = 0.055; {for long filterplates only at
                                              Z = 1 cm2V-1cm-1, 0 C, 1013 mb}
adsorptionratio = 0.867; {ratio of short and long filterplate adsorption}
edgeloss = 0.043; {loss of ions on the filter due to the edge effect}
noisefactor = 0.75; {experimental value}
c_powervoltage = 0.005062;  {powervoltage / ADC_counts}
c_filtervoltage = 0.1982; {filter voltage / ADC_counts}
standardpowervoltage = 24; {V, corresponds to the standardflowrate}
standardflowrate = 40; {dm3/s}
electrometerdelay = 222; {ms, time constant of the input circuit}
dlftolerance = 0.01; {permitted relative uncertainty of dlf verification}
flowzerocycle = 5; {primary adjustment of flow sensor zero}
flowzerohours : set of byte = [10, 22]; {hours of flow sensor zero adjustment}
```

The external constants are saved in the independent files BSMA3A.INI and BSMA3.DLF. The file BSMA3A.INI can easily be edited using the NC text editor. The original file should always be stored as a backup and the date in the heading of the INI-file must be changed to the date of editing. The version 20061115 of BSMA3A.INI is as follows:

```
BSMA3A.INI 20061115
 Includes external calibration coefficients,
 internal coefficients are presented in the program code.
 Any line beginning with a space is a comment.
 An assignment should be written without spaces.
 A space after the assignment starts a comment until the end of the line.
 Original text of BSMA3A.INI is attached into the end of BSMA3A.PAS
clockcorrection=0      diurnal correction (full seconds, up to +-25)
flowsensor=1           if 1 then calibration according to flowrate sensor
                            else calibration according to power voltage
cycletime=10           10 or 15 minutes
gainresistor=1499      ohm, gain = 1 + 50000 / R
balanceresistor=993    kohm, voltagecorrection = 25 / (25 + R / (2000 + R))
cpressurea=0.136       pressure (mb) = cpressurea * ADCcounts + cpressureb
cpressureb=107.5
ctemperaturea=0.0305   temperature (C) = ctemperaturea * ADCcounts + ctemperatureb
ctemperatureb=-0.5
chumiditya=0.021       humidity (%) = chumiditya * ADCcounts + chumidityb
chumidityb=-31
cflowrate=1.32         flowrate (L/s) = cflowrate * sqrt (dp:counts * T:K / p:mb)
balanceconstant=30     mobility channel 1 zero shift / electrometer gain
extrapath=A:\          external path for saving of diurnal tables and plottables,
                       external saving can be avoided writing here one symbol -
extension=xl           extension of the output file name, usually txt or xl
controls=1000          four symbols 0 or 1 setting initial values of controls:
                       datarecording, plottables, scandetails, and extrastorage
```

Additional comments to some external calibration constants:

Clockcorrection is necessary only in case of inexact internal clock of the computer. It allows correcting the clock once per day according to the value of the constant.

The control program adjusts the bridge balance automatically after every 10 or 15-minute cycle, displays the value on the computer screen and includes it into the output file. *Gainresistor* and *balanceresistor* are the values of two replaceable resistors inside of the instrument and they should be changed only when a resistor is actually replaced. Sensor calibration constants *cpressurea...cflowrate* should be changed only after recalibration of a sensor.

Extrapath is essential when the *extrastorage* regime is turned on. The regime can be turned on and off during the measuring process by means of control keys, indicated on the computer screen. *Extrapath* can be directed to a network disk or a removable media.

The file BSMA3.DLF consists of three numerical values: 1) ratio of the duration of the actual pause and the *delay* generated by Turbo Pascal, 2) 100 ms − (ADC measuring time) at the zero reading, 3) increase in the ADC measuring time per one count of the reading. The file is generated automatically by the program and should never be manually edited. All changes in BSMA3.DLF are recorded in the protocol TIMING.LOG.

4.3. Structure of a measuring cycle

The measurement is performed by self-contained cycles, which last for 10 or 15 minutes depending on the definition given in the file BSMA3A.INI. The beginnings of the cycles are synchronized with the beginnings of full hours. Before the first cycle preparative measurements of the air temperature, pressure, and flow rate are made, and the bridge balance is adjusted.

A cycle begins with the calibration operations described in the next section of the manual. Next, the mobility distribution is repeatedly scanned. About 19 seconds is required for one scan and a 10-minute cycle includes up to 30 scans. At the end of every cycle, the mobility and size distributions are calculated. The results are displayed on the screen and stored in the internal memory of the computer. The data collected during the day in the internal storage are saved onto the internal disk and can be saved additionally onto a network disk or removable disk at midnight.

The balance of the bridge is not perfect enough for the immediate use of a record of a single scan. Thus the short electrodes of the central sections of the inlet filter can be switched to the ground or to the voltage of 250 V by the control computer and used as the controlled inlet gates. Before every scan, the inlet gates are electrically closed or opened according to the measurement plan. Three regimes of the gates are marked in the plan as **+**, **−** and **0**:

+) inlet of negative ions is closed and inlet of positive ions is open,

−) inlet of negative ions is open and inlet of positive ions is closed,

0) inlets of negative and positive ions are both closed.

The regimes are alternated from scan to scan according to the plan of modulated measuring:

0 − 0 + 0 − 0 + 0 − 0 + 0 − 0 ...

The neighbor scans of every open-inlet scan are the zero measurements, which contain the same systematic errors as the open-inlet measurements. This allows removing the background signal according to the formula $x_i - (x_{i-1} + x_{i+1}) / 2$, where i is the index of an open-inlet scan, $i-1$ and $i+1$ are the indices of zero scans. The modulation of the ion input eliminates the systematic effect of the bridge misbalance, as well as all other systematic disturbances, which are not modulated when changing the voltage on the central sections of the inlet filter.

The random measurement error, called the measurement noise, is estimated comparing in a similar manner the zero scans $z_i = x_i - (x_{i-2} + x_{i+2}) / 2$, where i is the index of a zero scan. The noise index is calculated according to the standard deviation of the z_i over 10 central fractions (three first and three last fractions are dropped) during a cycle. The noise index was compared with the direct estimate of the measurement noise, which was found by means of a special experiment performed with permanently closed inlet gates and processed just in the same way as normal measurements. The comparison showed that the average measurement noise for 10 central fractions is approximately proportional to the standard deviation of z_i and the factor of proportionality is about 0.75. This factor in included into the set of internal calibration constants of the instrument.

One count of ADC corresponds to the fraction concentration of about 5 ions per cm^3. However, the digitalization error appears to be negligible because the fraction concentrations are calculated according to a large number of repeated measurements, which contain some amount of random noise.

The process of recording the electrometer signal during a scan is adjusted so that every measurement requires exactly 100 ms. The scans are performed according to a timetable, which is established individually at the beginning of every cycle during the calibration operation. A timetable consists of 17 numbers, which show how many 100 ms measurements of the electrometer signal should be made before the recording of the first mobility fraction and during the scanning of every following mobility fraction.

A typical 10-minute cycle contains 6 or 7 scans of positive and 6 or 7 scans of negative ions. At the end of the cycle the mean distributions are estimated according to the results of these scans. The noise of the electrometer signal has enlarged excess when compared with the Gaussian distribution. Thus, the simple arithmetic average is not the best estimate of the mean value. The improved estimate is computed according to the method of eliminated extreme values: the smallest and the largest members of the series are deleted before the average is calculated. The estimated distributions are related to the time, which is fixed in the middle of the cycle.

In the beginning of every scan the capacitor of the bridge should be recharged, which requires about one second. This time is used for recording of the signals of the sensors of flow rate, temperature, pressure, and relative humidity. Multiple measuring of the flow rate is important, because the pressure drop between the nozzles of the differential pressure sensor is influenced by strong turbulent fluctuations created after the narrow slit of the air flow calibration.

4.4. On-line adjusting of the calibration

The instrument should work in a wide range of the air temperature and pressure. Thus the temperature and pressure dependent calibration coefficients must be periodically corrected according to the actual conditions. The BSMA3 control program adjusts the calibration in every 10 or 15 minute cycle.

When all scans in a cycle are finished, the following procedures are performed:

- The current values of the flow rate, air temperature, pressure, and humidity are calculated according to the sensor signals collected during the cycle. The air flow rate is calculated according to the pressure drop considering the actual values of the air temperature and pressure.
- The inlet losses are calculated considering the actual values of the air temperature, pressure, and flow rate.
- Ion mobility fraction concentrations are calculated considering the actual values of the flow rate and inlet losses,
- Particle size fraction concentrations are calculated considering the dependence of the size-mobility conversion on the air temperature and pressure.

The results are stored and displayed.

Every new cycle starts with a special relaxation calibration scan when the high voltage on the aspiration condenser is recorded in the same way as the electrometer signal is recorded during the following measuring scans. The empiric calibration is necessary because the relaxation is not exactly exponential due to a second-order circuit inside of the high voltage source U3-6. The voltages, which correspond to the borders of the mobility fractions, are calculated considering the actual value of the air flow rate. Now the moments are determined when the voltage passes the values associated with the borders of the mobility fractions. The timetable for the following ion measuring scans is compiled according to the results of the relaxation calibration. The ADC readings of the analyzer voltage and the scanning timetable are displayed on the computer screen. The timetable remains valid during one cycle and it is renovated in every 10 or 15 minutes.

Additionally, in every cycle the power voltage and the bias of the electrometric amplifier are measured and the bridge balance is analyzed and corrected by means of the computer controlled resistor array.

The on-line measuring of the flow rate is an innovation in the BSMA3 and the reliability of the low-pressure sensor during long time measurements is unknown. Thus the control program enables to restore the flow rate depending adjustment of the calibration according to the fan voltage as it was made in the BSMA1 and BSMA2. The on-line data processing regime can be switched to the voltage-based adjustment by means of a corresponding parameter in the control file BSMA3A.INI.

4.5. Processing and saving the data

During a 10 or 15-minute cycle the electrometer signals are collected for every scan and for every analyzer voltage interval, which corresponds to a fraction mobility range. The data processing at the end of the cycle starts with calculating the necessary conversion factors. Then the zero level is corrected for every + and − scan according to the rule $x_i - (x_{i-1} + x_{i+1}) / 2$. The extreme values in the series of fractions corresponding to the different scans are deleted and the average values of remaining data are calculated. The average signals of electrometer are then converted to the values of the mobility fraction concentrations.

The size fraction concentrations are calculated on the basis of the table of mobility fraction concentrations. First, the boundaries of the size fractions on the mobility scale are calculated according to the algorithm by Tammet (1995), considering the actual air temperature and pressure. The boundaries are juxtaposed on the logarithmic scale of mobility as shown in example Figure 4.1. Next the concentrations of the size fractions are calculated using the linear interpolation on the logarithmic mobility scale and considering the possible versions of the topology of the fraction juxtaposition, which can differ from the presented example.

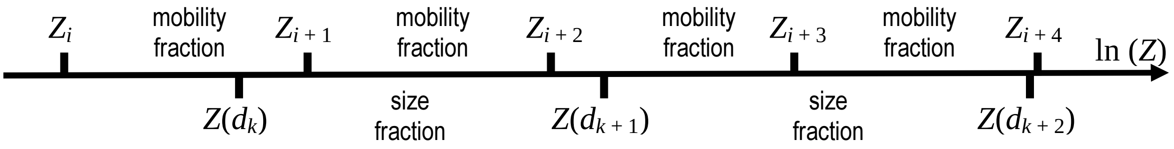


Figure 4.1. Juxtaposition of the boundaries of the mobility and size fractions.

Data are saved onto the internal disk of the control computer at the end of every cycle. Additionally, the tables of mobility and size fraction concentrations are collected during a day in the computer's internal memory. Processing and saving of these data onto external or internal disk is performed every midnight and during the shutdown procedure of the measurement, which is initiated by pressing the key combination of Ctrl+X. In addition to the tables of fraction concentration two special tables (one for positive and another for negative ions) are generated, which allow immediate creating of the diurnal contour plot of the ion size distribution by means of the MATLAB software. These extra tables are called the diagram tables or the plot tables.

The results are saved in the following order:

1. The monthly file of fraction concentrations with a meteorological and technical supplement is always saved into the subfolder MONTHS of the BSMA home folder on the internal hard disk of the control computer. A new file is initiated in the beginning of every month and it is appended after every cycle.

2. A new diurnal file of fraction concentrations with meteorological and technical supplement is initiated and saved at every midnight or when the measuring process is interrupted pressing the key combination Ctrl+X. This file is saved according to the user choice or onto the internal disk of the control computer or onto an external disk, with a path defined in the control file BSAM3A.INI. The user can change his choice at any moment using the computer keyboard. If the measuring is interrupted and restarted during a day, then the existing diurnal file is appended.

3. Two tables for creating of contour plots are saved at midnight or when the measuring process is interrupted pressing the key combination Ctrl+X. The files are saved according to the user choice or onto the internal disk of the control computer or onto an external disk, with a path is defined in the control file BSAM3A.INI. The user can make choice or cancel the saving of diagram tables at any moment using the computer keyboard. If the measuring is interrupted and restarted during a day, then the diagram tables consist of the data only for the last uninterrupted measuring period. In this case the tables for a full day can be generated afterwards using the diurnal or monthly main data file.

4. In case of a special request the full information collected during a cycle can be additionally saved in an unprocessed form. The corresponding file is called the table of scan details. It can be useful for the advanced technical diagnostics of the instrument only.

4.6. Information for a software developer

The introductory part of the control program contains two switches `developer` and `simulator`, both are initially set into the position "false".

When `developer` is true, then two hidden operations will be available. Both hidden operations are launched by pressing the key Z and corresponding procedures can be written or modified by the developer. One Z-operation is accessible in the test regime, search for the phrase "`: if developer`" in the program code. In the present version of the control program the procedure `sensorcalibration` is activated when pressing Z in the test regime. Two more developer procedures `electrometertransition` and `flowratetransition` have still been left in the program code, although they are never called in the program. The second Z-operation is available from the start menu despite the fact that Z is not shown in display. This operation launches a special procedure (search for "`Extratest`" in the program code), the content of which should be modified to perform the desired special operation.

The key combination Ctrl+F in the developer regime forces an interruption of measuring process, which normally can happen only in a failure situation.

The switch `developer` increases the number of decimals in some output values, such as the flow rate; search the program code for "`if developer`".

The switch `simulator` is used for speed-up the testing of the program fragments. If `simulator` is true, then the program does not communicate with the BSMA and can be used without connecting the computer with the real instruments. The time-consuming operations are skipped and a cycle is performed ten times faster than it would be possible in the real regime. The ADC signals are numerically simulated imitating a fictive mobility distribution of ions. Search the phrase "`if simulator`" in the program code to see the differences compared with the normal regime.

The editing but not the testing of the program code can be made under WINDOWS using the DELPHI editor, which is more convenient when compared with the TURBO editor. The control program can be tested in simulator regime when running TURBO PASCAL in a window of any version of WINDOWS. Unfortunately, the real regime cannot be tested under NT-based WINDOWS because BSMA2A requires direct access to the LPT port.

The instrument itself does not contain any internal data processing units and can be controlled with a computer running under WINDOWS XP. For this the PICO ACD-16 must be replaced by a better data acquisition unit, which has at least 8 standard digital outputs and 8 analog inputs. The analog inputs must be bipolar, have at least 8191 counts per 2.5 V input, and able to perform at least 25 measurements per second. The control program must be rewritten in a proper platform e.g. DELPHI or LABVIEW. The main changes in the control program should be:

- the global procedure *Setcontrols* and the procedure *setport* in the procedure *test* should be replaced considering the specific data acquisition unit;
- the global functions *ADC* and *ADCoriginal* should be replaced considering the specific data acquisition unit;
- the timetable structure of the mobility scanning (see procedures *calibration* and *scan* in *Measurement*) could be replaced with a simple structure, where the electrometer output and the voltage of the aspiration condenser are alternately monitored, and switching from one mobility fraction to the next fraction is made when crossing the voltage border between the two fractions during a scan;
- all operations writing on the screen and reading from the keyboard should be rewritten considering the possibilities of the specific programming environment.

5. CALIBRATION OF THE INSTRUMENT

5.1. Geometric parameters of the aspiration condenser

The ion currents in an aspiration condenser can be expressed in terms of air flow rate or in terms of average air velocity u over the collector electrode. Immediately measurable parameters are the full air flow rate Q and the geometric dimensions: distance between electrodes h and width of air channel w. Full air flow corresponds to 4 spaces between the electrodes (the BSMA contains two two-sided condensers). However, the flow rate is not exactly equal to the product $4uhw$ because of air displacement from the boundary layer on the side insulators of the condenser. An improved equation is $Q = 4uhw_h$, where $w_h = (w - 2\delta_{disp})$ is the hydrodynamic effective width of the condenser. The displacement thickness (see Incropera and Dewitt, 2002) is estimated as

$$\delta_{disp} = 1.72 \sqrt{(\nu\, L_u / u)}, \tag{5.1}$$

where ν is the kinematic viscosity of air and L_u is the average distance from the beginning of the air channel. In the BSMA3 the arguments are roughly estimated $\nu = 1.5\times10^{-5}$ m^2/s, $L_u =$ 0.15 m, and $u = 1.8$ m/s, which result in $\delta = 1.9$ mm. Thus the boundary layer displacement is a very small correction to the width of the condenser.

The geometric parameters of the BSMA3 are: $h = 22.75$ mm, $w = 240$ mm, $w_h = 236.2$ mm, the electrostatic effective width of the collector electrode $w_c = 161.5$ mm, and the effective length of the aspiration condenser $L_c = 110.8$ mm, see Figure 2.4. Calibration factors of the BSMA are determined considering the standard air flow rate $Q_o = 40$ dm^3/s and corrected in every cycle according to the current air flow rate Q , which is usually 1−2% less than the fixed value of Q_o.

5.2. Conversion of ion current and analyzer voltage

Immediate output of measurements is expressed in ADC counts, related to the ADC input voltage V as ADC = $c_{\mathrm{ADC}}\, V$. The output of the electrometric amplifier is $V = g_E\, R_E\, I$, where g_E is the gain of the electrometric amplifier, R_E is the input resistance, and I is the collector current. In the electrometric channel

$$\mathrm{ADC_E} = c_{\mathrm{ADC}}\, g_E\, R_E\, I. \tag{5.2}$$

The analyzer high voltage is connected to the ADC via a voltage divider and $V = k\, V_{HV}$, where k is the transfer coefficient of the divider. In the high voltage channel

$$\mathrm{ADC_{HV}} = c_{\mathrm{ADC}}\, k\, V_{HV}\,. \tag{5.3}$$

The signal transfer parameters of the BSMA3 are: $c_{\mathrm{ADC}} = 8191 / 2.5 = 3276.4$ V^{-1} and $R_E = 5.0$ GΩ. The electrometer gain is

$$g_E = 1 + 50\ \mathrm{k\Omega} / R_g\,, \tag{5.4}$$

where R_g is the resistance of a replaceable resistor. The actual value of R_g is included into the set of the external calibration data. A typical value of the gain is about 34.

Calibration factors of BSMA3 are determined considering the standard value of the high voltage transfer coefficient $k_o = 39 / 49900 = 7.816\times10^{-4}$. The coefficient k is slightly corrected in the BSMA3 on-line data processing considering the actual value of the balance adjustment resistor. The actual value of the voltage transfer coefficient is

$$k = k_o / (1 + 0.04 / (1 + 2\ \mathrm{M\Omega} / R_b)), \tag{5.5}$$

where R_b is the resistance of the replaceable balance adjustment resistor, which value is available in the set of the external calibration data.

5.3. Voltage factor

In the BSMA internal data processing the voltages of aspiration condensers are set according to the desired electric mobility Z and calculated in ADC units:

$$\mathrm{ADC}_{\mathrm{HV}} = (\mathrm{VF} / Z) \times (k / k_{\mathrm{o}}) \times (Q / Q_{\mathrm{o}}), \qquad (5.6)$$

where VF is the voltage factor and k is the actual value of the voltage divider coefficient. Ratios k / k_{o} and Q / Q_{o} include only minor corrections and their values are close to the unity. Central mobility is expressed in the theory of the aspiration condenser

$$Z = h^2 u / (L_c V_{HV}) = h Q / (4 w_h L_c V_{HV}) \qquad (5.7)$$

Substitution of expressions (3) and (5) into Equation (4) results in

$$\mathrm{VF} = c_{\mathrm{ADC}} k_{\mathrm{o}} h Q_{\mathrm{o}} / (4 w_h L_c) = 223 \, cm^{-2} V s. \qquad (5.8)$$

The ratio k / k_{o} does not vary during a measuring session. Thus the voltage coefficient $\mathrm{VF}\times(k / k_{\mathrm{o}})$ is used inside the BSMA3 control program and only the quotient Q / Q_{o} is adjusted in every measuring cycle.

5.4. Concentration factor

The concentration of ions in a mobility fraction n_i is calculated during the BSMA internal data processing according to the ADC counts of electrometric channel in the following way:

$$n_i = \mathrm{CF} \times (\mathrm{ADC}_{\mathrm{E}} / g_E) \times (Q_{\mathrm{o}} / Q) / P, \qquad (5.9)$$

where g_E is the electrometer gain, Q is the actual air flow rate, and P is the inlet penetration. The calibration coefficient CF is called the concentration factor. The electric current collected by the collector electrode is

$$I = 1.01 \, P \, e \, n_i \, Q_{\Delta}, \qquad (5.10)$$

where e is the elementary charge and Q_{Δ} is the flow rate of the air passing the inlet slit and flowing over the collector electrode. The analyzer has 16 slits and

$$Q_{\Delta} = (Q / 16) (w_c / w_h). \qquad (5.11)$$

Successive substituting of (9) into (8), (8) into (2), and (2) into (7) results in

$$\mathrm{CF} = 15.84 \, w_h / (c_{\mathrm{ADC}} R_E \, e \, w_c \, Q_{\mathrm{o}}) = 221 \ \mathrm{cm}^{-3}. \qquad (5.12)$$

The electrometer gain does not vary during a measuring session. Thus the concentration coefficient CF/g_E is used inside the BSMA3 control program and only the quotient $(Q / Q_{\mathrm{o}})/P$ is adjusted in every measuring cycle.

5.5. Direct calibrating the air flow sensor

The air flow is continuously monitored in the BSMA3 by means of a Honeywell ultralow differential pressure sensor 164PC01D76. The sensor is connected between two nozzles. The high pressure nozzle is opened to the internal space of the aspiration condenser and the low pressure nozzle is located behind the flow calibration slit in the metal sheet separating the fan section in the instruments from the condenser section, see Figure 5.1. The flow rate is calculated in every measuring cycle according to equation

$$Q = \mathrm{CQ} \sqrt{((\mathrm{ADC}_{\mathrm{Q}} - \mathrm{ADC}_{\mathrm{Q0}}) \, (T{:}\mathrm{K}) / (p{:}\mathrm{mb}))} \ \mathrm{dm}^3\mathrm{s}^{-1}, \qquad (5.13)$$

where CQ is the coefficient called *cflowrate* in the calibration file BSMA3A.INI, $\mathrm{ADC}_{\mathrm{Q}}$ and $\mathrm{ADC}_{\mathrm{Q0}}$ are the ADC-readings of the differential pressure sensor at the actual air flow and zero air flow, $(T{:}\mathrm{K})$ is the numerical value of temperature in the Kelvin scale and $(p{:}\mathrm{mb})$ is the numerical value of the atmospheric pressure in millibars or hectopascals. The calibration experiments ware made using the rotary gas flow meter PC-400, the measuring range of which is up to 111 $\mathrm{dm}^3\mathrm{s}^{-1}$. The flow meter counts the fixed-volume air parcels passed through the instrument and its calibration is expected to change only as a result of mechanical wearing. The first indication of wearing is usually the increased friction of the rotor. The time of free inertial rotating of about 100 s validated the good condition of the instrument. The BSMA3 air flow was measured using the compensation method: air was blown into a large box through the flowmeter by means of an extra fan, the flow was controlled by a mechanical slide, and sucked out from the box by the BSMA3. One side of the box is made of thin plastic film, which helps exactly balance the pressure in the box by adjusting the slide. Calibration setup is shown in Figure 5.2. According to the results the value of the calibration coefficient is estimated CQ = 1.34.

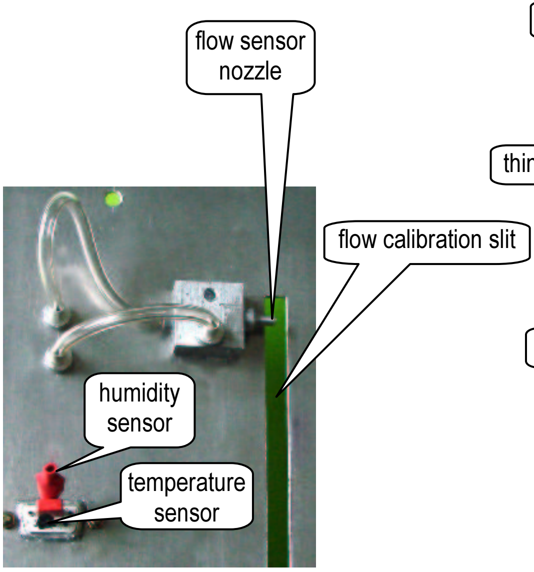


Figure 5.1. BSMA3 sensors.

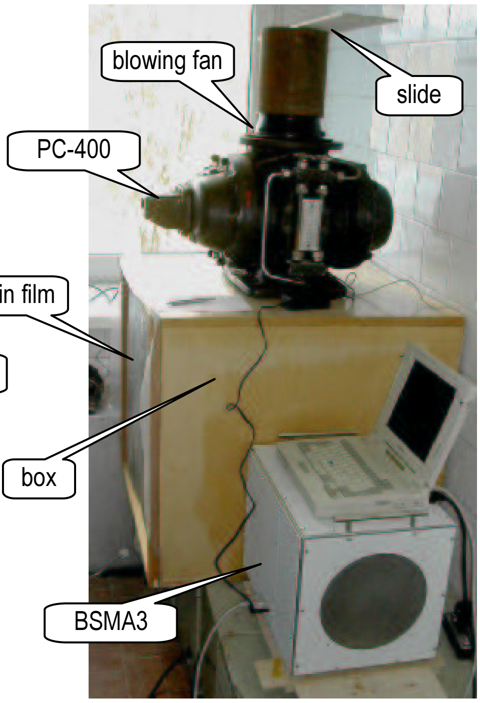


Figure 5.2. Air flow calibrating setup.

5.6. Calibrating the sensors

Temperature and humidity sensors are located in the fan section of the instrument as shown in Figure 5.1. The air mass flow rate through the instrument is about 50 g/s and the 20 W heat emission inside of the BSMA3 analyzer section increases the air temperature about 0.4 K. If the instrument is located in a warm room and the outside air is cold, then an additional increase in the temperature is caused by the heat flux through the cover of the instrument. The inside of the cover panels is coated with 1 cm styropor sheets to keep the heat flux low. Thus the parameters of the air near the sensors are close to the parameters of the outside air.

Air temperature is measured by the National Semiconductor sensor LM35 and calculated according to the ADC_T:

$T : C = ctemperaturea \times ADC_T + ctemperatureb,$

where *ctemperaturea* and *ctemperatureb* are the calibration coefficients presented in BSMA3A.INI. One volt of the sensor output corresponds to $ADC_T = 3276$ in the BSMA3, and the coefficients calculated according to the factory calibration of LM35 are:

ctemperaturea = 0.0305 and *ctemperatureb* = 0.

The coefficients can be adjusted when the values of ADC_T are exactly measured at two different temperatures:

$ctemperaturea = (ADC_{T1} - ADC_{T2}) / (T1 - T2),$

$ctemperatureb = T1 - ctemperaturea \times ADC_{T1}.$

The calibration experiment showed that the factory value of *ctemperaturea* is valid in the BSMA3, but *ctemperatureb* is about −0.5 probably due to the air heating during the passage through the instrument. The experience of long-time exploitation of similar instruments shows that the calibration of the temperature sensor should be checked and adjusted once a year.

The calibration coefficients of the sensors of relative humidity and atmospheric pressure can be recalculated according to calibration measurements in a similar way as the calibration coefficients of the temperature sensor.

Relative air humidity is measured by the Honeywell sensor HIH-3610. The calibration of the humidity sensor appeared to be pretty unstable. It is recommended to recalibrate the sensor every few months and replace it after one or two years of routine measurements.

Calculation of the relative humidity RH includes the temperature correction:

$\mathrm{RH} = (chumiditya \times \mathrm{ADC_H} + chumidityb) / (1.0546 - 0.00216\ \mathrm{T:C})$

One volt of the humidity sensor output corresponds to $\mathrm{ADC_H} = 1638$ in the BSMA3, and the coefficients calculated according to the factory calibration of HIH-3610 are:

$chumiditya = 0.0194$ and $chumidityb = -27.4$.

The initial calibration of the BSMA3 sensor was adjusted comparing the readings of $\mathrm{ADC_H}$ with measurements made by an aspiration psyhrometer. The values of the calibration coefficients written into the first version of BSMA3.INI are

$chumiditya = 0.02$ and $chumidityb = -28$.

The atmospheric pressure is measured by the Motorola/Freescale sensor MPX5100A. The sensor is located on the main PC board in the analyzer section of the instrument. Pressure is calculated as

$p : \mathrm{mb} = cpressurea \times \mathrm{ADC_p} + cpressureb$,

One volt of the pressure sensor output corresponds to $\mathrm{ADC_p} = 1638$ in the BSMA3, and the coefficients calculated according to factory calibration of MPX5100A are:

$cpressurea = 0.136$, $cpressureb = 106$

The values of the coefficients were adjusted comparing the measurements with the readings of a mercury barometer. The adjusted values are:

$cpressurea = 0.136$, $cpressureb = 107.5$

5.7. Measuring the ion loss on the inlet grid

The constant of the adsorption of ion on the inlet grid A_{grid} is defined in the section 3.2 and used in numeric compensation of the inlet losses of ions according to Equation (3.15). The value of *grid_asorptioncoefficient* is presented in the set of internal calibration coefficients.

The BSMA3 inlet grid is made of a perforated sheet and we have no exact methods for theoretical estimation of the adsorption coefficient. Thus the adsorption on the grid is measured experimentally.

An additional grid of the same structure was used in the experiment. The area of the additional grid was bigger when compared with the BSMA3 inlet grid, resulting in decreased air velocity and increased adsorption, which is favorable for the exactness of the experiment.

The experiment was made using a stable air ion source, which delivers the flow of homogeneously ionized air with the flow rate of more than twice the flow rate in the BSMA3. The setup of the experiment is shown in Figure 5.3. The area of the additional grid was twice the area of the BSMA3 inlet grid, which results in lower linear velocity and 1.4 times higher relative adsorption. During the experiment the additional grid was repeatedly installed or removed after every half hour. Relative loss of ions was calculated comparing the BSMA3 records for the two dominating fractions of positive ions (average mobility 1.27 $\mathrm{cm^2V^{-1}s^{-1}}$) and for the two dominating fractions of positive ions (average mobility 1.7 $\mathrm{cm^2V^{-1}s^{-1}}$). 10% of positive ions and 12.7% of negative ions were lost on the additional grid in the conditions of the experiment. The relative losses reduced to the standard conditions, standard mobility 1 $\mathrm{cm^2V^{-1}s^{-1}}$, and actual air velocity on the BSMA3 grid, are 6.0% and 6.2%. On the ground of these results the value of calibration constant $c_{grid} = 0.06$ is used in Equation (3.16) when processing the data in the control program of BSMA3.

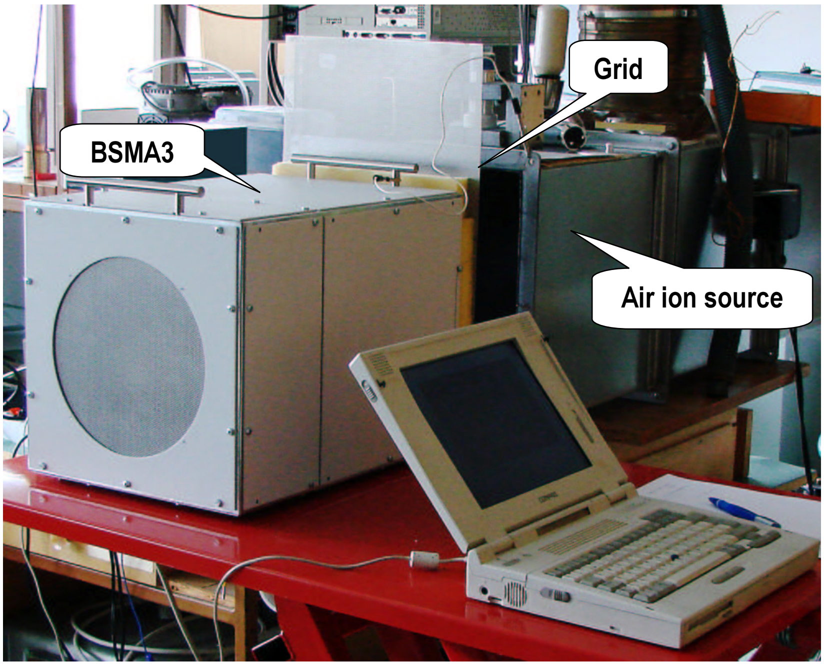


Figure 5.3. BSMA3 with the additional grid near the outlet of the stable air ion source.

5.8. Iodine test and comparison with an integral air ion counter

The admixture of iodine vapor in the clean air forms negative ions of the reduced mobility 1.75 $cm^2V^{-1}s^{-1}$ (Tammet, 1975). When restored according to the Langevin rule to the laboratory conditions, the peak in the mobility distribution of negative ions is expected at the mobility of about 1.88 $cm^2V^{-1}s^{-1}$. Recording of the peak of the iodine mobility is a method of checking the calibration of a mobility analyzer. The BSMA3 has low resolution and allows only approximate estimating the peak in the mobility distribution.

The measurements were performed in the laboratory air on 20061106 and on 20061115. The stable ionization was generated by means of beta-radiation of a weak Sr-90 preparation. Both experiments show the peak between 1.9−2.0 $cm^2V^{-1}s^{-1}$ when calculated on basis of the direct air flow calibration. The result suggests a hypothesis that the gas flow meter PC-400 shows slightly increased value of the flow rate. The calibration of a new commercial gas flow meter can be intentionally shifted with an aim to increase the service life of the instrument.

The BSMA3 was compared with the integral ion counter UT8401 using the same stable air ion generator as in the grid adsorption experiment. The results are in Table 5.1.

Table 5.1.

Comparison of the BSMA3 and the integral counter of air ions

	UT8401	BSMA3	Ratio
Positive cluster ion concentration	28300	26900	1.05
Negative cluster ion concentration	23400	22300	1.05

The uncertainty of the integral counter calibration exceeds 5%. The differences in Table 5.1 remain within the limits of the uncertainty. However, we have again an indication of possible overestimating the flow rate by rotary gas flow meter PC-400.

On the basis of the experiments the calibration coefficient CQ, which was estimated 1.34 according to the direct air flow measurements, is corrected and a slightly decreased value

$$CQ = 1.32$$

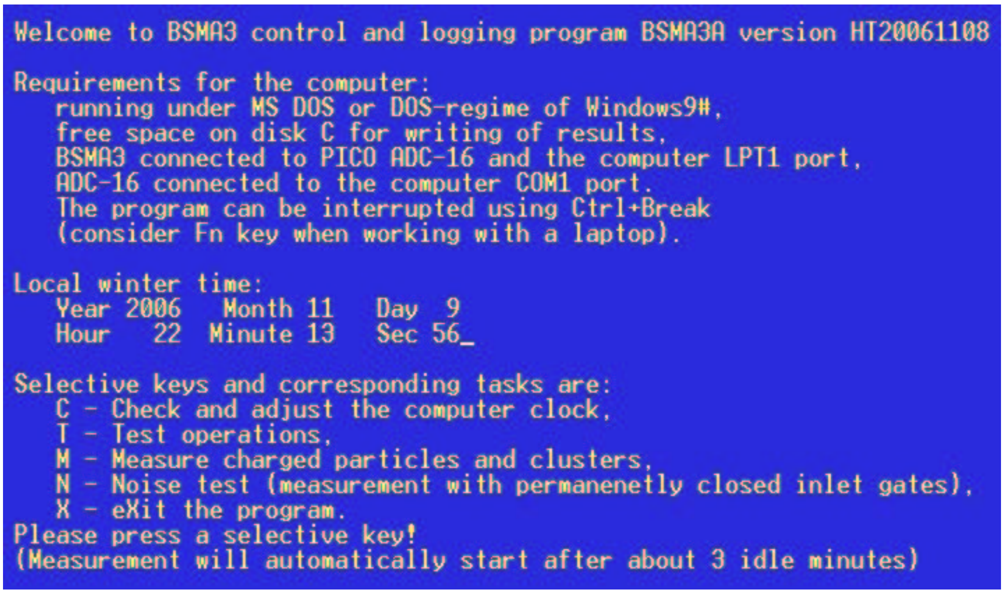
is accepted as the merged calibration coefficient of the BSMA3 and included into the calibration file BSMA3A.INI.

6. ROUTINE MEASUREMENTS

6.1. Launching of the measuring process

We expect that the BSMA3, the control computer and ADC are connected and the program BSMA3A is installed as explained in Chapter 8 of the present manual. The standard startup procedure activates the folder C:\BSMA, which includes the program file BSMA3A.EXE, calibration data BSMA3A.INI and BSMA3.DLF, protocol of the timing corrections TIMING.LOG, subfolders for measurement results MONTHS, DAYS, TABLES, DETAILS, and subfolder for auxiliary programs TOOLS. Additionally, the source code BSMA3A.PAS and a folder called VARIA can be presented in the home folder C:\BSMA.

The computer and the BSMA can be switched on at the same time. If the control computer is prepared according to section 8.2 of the manual then the MS DOS and the control program BSMA3A will be automatically launched after the switch-on. The program uses the first two minutes for checking of the timing calibration and indicates the interim results of this process. When the checking procedure is finished, the following picture appears:



```
Welcome to BSMA3 control and logging program BSMA3A version HT20061108

Requirements for the computer:
   running under MS DOS or DOS-regime of Windows9#,
   free space on disk C for writing of results,
   BSMA3 connected to PICO ADC-16 and the computer LPT1 port,
   ADC-16 connected to the computer COM1 port.
   The program can be interrupted using Ctrl+Break
   (consider Fn key when working with a laptop).

Local winter time:
   Year 2006   Month 11   Day  9
   Hour   22  Minute 13   Sec 56_

Selective keys and corresponding tasks are:
   C - Check and adjust the computer clock,
   T - Test operations,
   M - Measure charged particles and clusters,
   N - Noise test (measurement with permanenetly closed inlet gates),
   X - eXit the program.
Please press a selective key!
(Measurement will automatically start after about 3 idle minutes)
```

Figure 6.1. Start menu of BSMA3A.

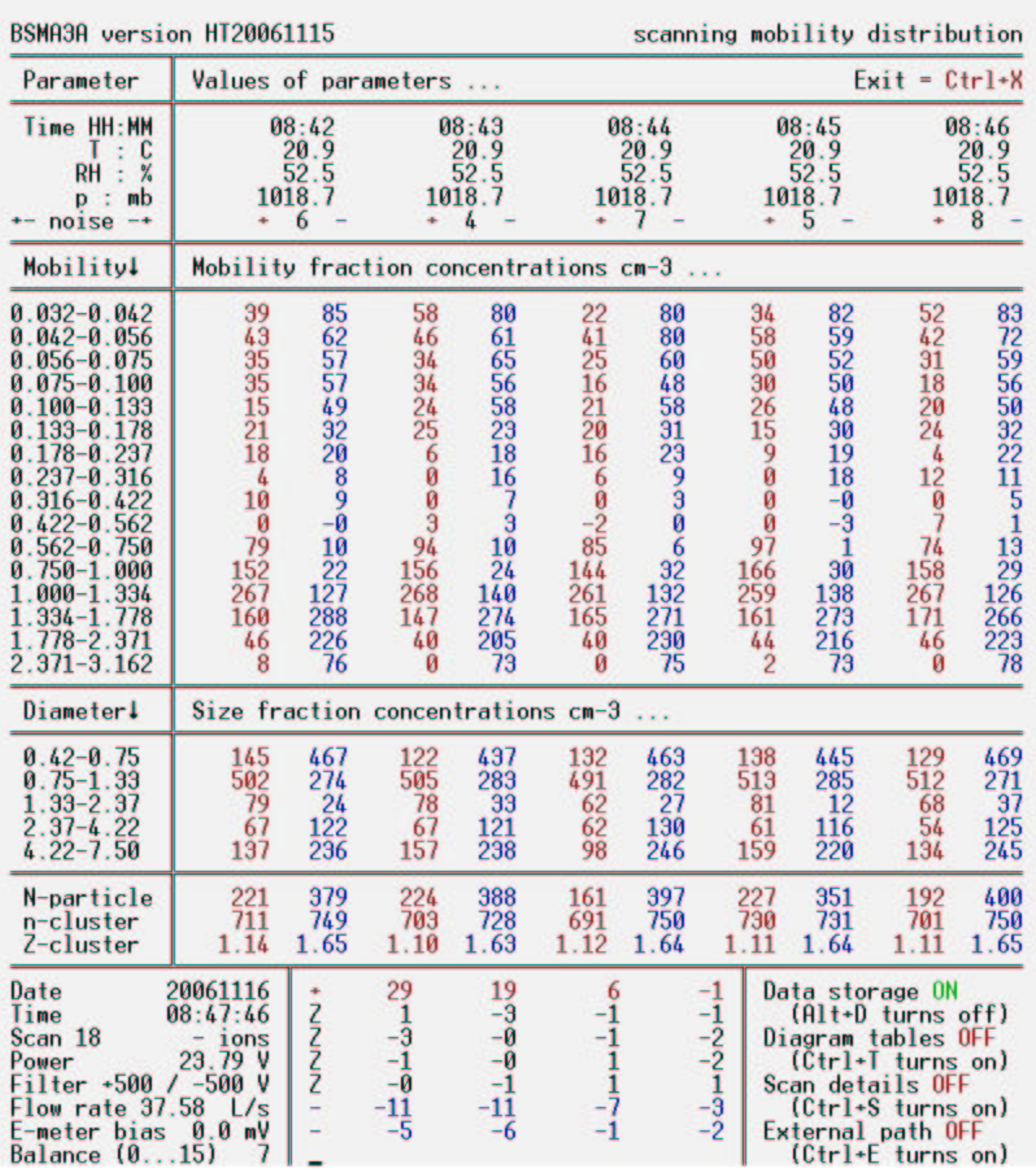
Usually, the local civil winter time is used when recording the measurements. If the time shown on the screen is not exact, then the key C should be pressed first. This allows adjusting the computer clock. If the computer clock has a systematic error, then the clock can be automatically adjusted every day during the uninterrupted routine measurements. The automatic diurnal clock correction should be shown in the file BSMA3A.INI.

Measuring can be launched pressing the key M. After waiting for 3 minutes without pressing any key, the measuring process is launched automatically. This option is supports automatic continuing of the measurement after a temporary blackout of mains voltage.

6.2. Control of the BSMA3 during measuring

During the measurement, the computer screen gradually fills with information as shown in Figure 6.2. This screen image is a formal example generated using a measurement simulator and the numbers in the figure do not correspond to any realistic situation.

The possibilities of interaction with the control program during the routine measuring process are limited. All active controls are shown on the screen. The event of pressing a Ctrl- or Alt-key is always promptly noticed by the computer, but the program will delay its reaction until a proper moment, as a rule until the end of a scan. If two or more control keys are pressed before the reaction of the computer, then only the last key is considered as valid.



```
BSMA3A version HT20061115                             scanning mobility distribution
═════════════════════════════════════════════════════════════════════════════════════
 Parameter   ║ Values of parameters ...                                 Exit = Ctrl+X
═════════════════════════════════════════════════════════════════════════════════════
 Time HH:MM  ║       08:42        08:43        08:44        08:45        08:46
      T : C  ║        20.9         20.9         20.9         20.9         20.9
     RH : %  ║        52.5         52.5         52.5         52.5         52.5
      p : mb ║      1018.7       1018.7       1018.7       1018.7       1018.7
 +- noise -+ ║      +  6  -      +  4  -      +  7  -      +  5  -      +  8  -
═════════════════════════════════════════════════════════════════════════════════════
 Mobility↓   ║ Mobility fraction concentrations cm-3 ...
═════════════════════════════════════════════════════════════════════════════════════
0.032-0.042  ║    39     85    58     80    22     80    34     82    52     83
0.042-0.056  ║    43     62    46     61    41     80    58     59    42     72
0.056-0.075  ║    35     57    34     65    25     60    50     52    31     59
0.075-0.100  ║    35     57    34     56    16     48    30     50    18     56
0.100-0.133  ║    15     49    24     58    21     58    26     48    20     50
0.133-0.178  ║    21     32    25     23    20     31    15     30    24     32
0.178-0.237  ║    18     20     6     18    16     23     9     19     4     22
0.237-0.316  ║     4      8     0     16     6      9     0     18    12     11
0.316-0.422  ║    10      9     0      7     0      3     0     -0     0      5
0.422-0.562  ║     0     -0     3      3    -2      0     0     -3     7      1
0.562-0.750  ║    79     10    94     10    85      6    97      1    74     13
0.750-1.000  ║   152     22   156     24   144     32   166     30   158     29
1.000-1.334  ║   267    127   268    140   261    132   259    138   267    126
1.334-1.778  ║   160    288   147    274   165    271   161    273   171    266
1.778-2.371  ║    46    226    40    205    40    230    44    216    46    223
2.371-3.162  ║     8     76     0     73     0     75     2     73     0     78
═════════════════════════════════════════════════════════════════════════════════════
 Diameter↓   ║ Size fraction concentrations cm-3 ...
═════════════════════════════════════════════════════════════════════════════════════
 0.42-0.75   ║   145    467   122    437   132    463   138    445   129    469
 0.75-1.33   ║   502    274   505    283   491    282   513    285   512    271
 1.33-2.37   ║    79     24    78     33    62     27    81     12    68     37
 2.37-4.22   ║    67    122    67    121    62    130    61    116    54    125
 4.22-7.50   ║   137    236   157    238    98    246   159    220   134    245
═════════════════════════════════════════════════════════════════════════════════════
 N-particle  ║   221    379   224    388   161    397   227    351   192    400
 n-cluster   ║   711    749   703    728   691    750   730    731   701    750
 Z-cluster   ║  1.14   1.65  1.10   1.63  1.12   1.64  1.11   1.64  1.11   1.65
═════════════════════════════════════════════════════════════════════════════════════
Date          20061116 ║ +     29      19       6      -1 ║ Data storage ON
Time          08:47:46 ║ Z      1      -3      -1      -1 ║   (Alt+D turns off)
Scan 18         - ions ║ Z     -3      -0      -1      -2 ║ Diagram tables OFF
Power          23.79 V ║ Z     -1      -0       1      -2 ║   (Ctrl+T turns on)
Filter +500 / -500 V   ║ Z     -0      -1       1       1 ║ Scan details OFF
Flow rate 37.58  L/s   ║ -    -11     -11      -7      -3 ║   (Ctrl+S turns on)
E-meter bias  0.0 mV   ║ -     -5      -6      -1      -2 ║ External path OFF
Balance (0...15)     7 ║ _                                ║   (Ctrl+E turns on)
```

Figure 6.2. Computer screen during a simulated measurement.

The possibility to switch the data storage off is used on the occasion of service operations like the cleaning of the BSMA inlet grid when the data would be disturbed. The keys Ctrl+D and Alt+D control the storing of the data in the computer RAM and do not affect the midnight writing of data onto the disk. The writing onto the disk is skipped only in case of absolutely empty diurnal data storage in RAM.

The key combinations Ctrl+E and Alt+E control the path of writing the diurnal data tables and the tables for plotting the diagrams. Pressing of Ctrl+E directs the writing onto the external folder, which path is shown in BSMA3A.INI. Otherwise, the tables are written into the standard internal folders DAYS and TABLES. The writing of the diagram tables can be at all prevented by the key combination Alt+T, but the diurnal standard tables are always saved onto the external media or onto the internal disk of the control computer.

The key combination Ctrl+S allows saving the detailed table of results for every scan inside a cycle. The scan details are physically appended to a corresponding file in every cycle while all other results are physically saved only at midnight or at the exit of the program. The table of scan details is usually switched off; it may be needed only for advanced diagnostics of the instrument and for the developer of the control program.

The initial positions of the control keys are set by the control file BSMA3A.INI and can be changed when editing this file.

The measurements can be disturbed due to different reasons. Typical disturbances are: pollution on insulators of the aspiration condenser, condensing of water inside the condenser, tiny ice crystals in the air etc. If a diagnostic parameter is out of the critical range, then its value is displayed in blinking red. The critical ranges are:

- power voltage 21...26 V,
- flow rate 32...42 dm^3/s,
- filter voltage 450...520 V,
- electrometer bias −5...5 mV,
- balance index 1...14,
- number of measurements in a fraction at least 6,
- number of electrometer overload events during one scan up to 2.

Some disturbances can harm the instrument. In this case the measuring is stopped, voltage of the aspiration condenser and the air flow are switched off, and a blinking red failure message appears. The grounds of the failure are briefly indicated in the message:

- *filter voltage* : the voltage of a filter is out of range, the probable reason being polluted and wet insulation of the filter,
- *corrupted HV* : the number of measurements in a fraction appears less than 6 probably due to the polluted and wet insulators of the aspiration condenser,
- *electrometer overload* : electrometer signal is out of range more than twice in a cycle, probable reasons are fine droplets or ice crystals in the air or polluted and wet insulators of the aspiration condenser.

The control program will continue to check the parameters and make attempts to restart the measuring process every full hour.

More information about the diagnostics of the instrument is presented in Sections 8.5 and 8.6 of the manual.

6.3. Terminating of the measuring process and data capture

The measuring procedure is terminated after pressing Ctrl+X. The measuring is stopped at the end of the current scan and the results of the cycle are not completed. When the measuring is stopped for a short action, e.g. copying of the data, then it can be restarted again after a few minutes and the results of only one cycle are lost.

The exit key does not work during the preparative operations, which are performed immediately after launching the program. During these operations, the program can be interrupted only using a universal interruption combination Ctrl+Break.

After the measurement procedure has been stopped, the screen picture Figure 6.1 appears again, but without the last line: the automatic launch of measurement is blocked. Now it is possible to perform supporting operations (adjusting the clock, noise recording, test operations), restart the measurement or completely exit the program by pressing X without Ctrl.

In case of the standard software installation (see Chapter 8 of the present document) the *Norton Commander* (NC) launches automatically after the exit of the measurement program. This allows copying the data from the data folders to the network disk or to a removable media e.g. a floppy disk. NC allows copying a data file as it is or as a zip-compressed file. When the data have been copied, BSMA3A can be started again as follows:

select the folder C:\BSMA\ using NC,

select BSMA3A.EXE in the NC window and press ENTER.

When the measuring is not running then the computer can be switched off at any time, because the MS-DOS does not require special shut down procedure. However, when the computer is switched off during the measuring process without pressing the key combination Ctrl+X, the data collected during the current day in the computer RAM for the diurnal file and the diagram table is lost. This can happen at a blackout of the mains voltage. The data loss may be not total, because the data are physically saved into the monthly file at the end of every cycle and if this file is not corrupted then the data are still available. However, there is a small probability that blackout happens just in the moment of physical writing the data and the file is corrupted. Thus, the UPS power is recommended in case of routine measurements.

After having exited the control program the power of the BSMA3 can be switched off simultaneously with the computer or before switching off the computer.

7. OUTPUT OF THE BSMA3 AND DATA PROCESSING

7.1. Output files

The measuring program writes one file per month into the folder C:\BSMA\MONTHS\. The filename is 3AYYMM00.XL, where YY is replaced by a number showing the year and MM by a number showing the month (example: 3A061100.XL). The computer adds new data into the end of the file every midnight and after pressing the exit key combination Ctrl+X. If the program does not find the file of the running month, then a new file will be initiated. This happens always in the beginning of a new month.

The file 3AYYMMDD.XL (DD shows the day) in the folder C:\BSMA\DAYS or in the external folder is written every midnight. The diurnal files on the computer internal disk can be considered as a backup copy of the information saved in 3AYYMM00.XL

Storing of the data can be temporarily cancelled pressing Alt+D, which is usually done during the servicing of the instrument or a specific test measurement. The data storing regime is restored after pressing Ctrl+D. The computer does not immediately respond to the pressed key combination, the response is delayed until the end of the running 20-second scan period.

When Ctrl+S is pressed, then the computer saves the detailed information gathered during individual scans in the end of every 10 or 15 minute cycle. This information is saved into the diurnal file 3SYYMMDD.XL in the folder C:\BSMA\DETAILS\. During normal measurements, the saving of the details is turned off, because the files 3SYYMMDD.XL are large and necessary only for special advanced diagnostics of the instrument performance.

The folder C:\BSMA\TABLES\ is a default folder for special data tables prepared for usage as immediate source information for contour plots. Making of the contour plots is described in the section 7.4 of the manual. When the Ctrl+T regime is activated, then two files pYYMMDD.XL (positive ions) and nYYMMDD.XL (negative ions) are saved every midnight.

An alternative way to make the contour plots is to create the diagram table files on the basis of the main data file 3AYYMM00.XL or 3AYYMMDD.XL by means of a separate program DIATAB.EXE.

The files pYYMMDD.XL and nYYMMDD.XL can be saved into the internal folder C:\BSMA\TABLES\ or another folder specified in the file BSMA3A.INI. This folder can be a network folder or a folder on a removable media. The saving of the diagram tables can be cancelled pressing Alt+T on the keyboard and restored pressing Ctrl+T.

All data files contain tab-delimited text tables. They can be browsed and analyzed using MS Excel or Notepad. The data structure is similar to the output data of the control programs BSMA2E1 and BSMA2E2, which are used controlling the instruments BSMA1 and BSMA2. The differences are pointed out in the following section.

7.2. Structure of the main data table

3AYYMM00.XL or 3AYYMMDD.XL consists of one header line and following data lines for every 10- or 15-minute measuring cycle. The structure of monthly files and diurnal files is the same, as well as the structure of the file of hourly averages. The header consists of 64 tab-delimited words and every data line consists of 64 numerical values. Most of the values are presented as whole numbers and a few values contain the point-separated decimal part. The columns of the table are explained in Table 7.1.

Table 7.1.

Columns of the main data table

No	Header	Value	Sign	Range: nm or $cm^2V^{-1}s^{-1}$
1	YYMMDD	Date YYMMDD		
2	HHMM	Time HHMM (center of the interval)		
3	DAY	Day of year (3 decimal places)		
4	T:C	Temperature, ºC (1 decimal place)		
5	RH:%	Rel. humidity, % (1 decimal place)		
6	p:mb	Air pressure, mb (1 decimal place)		
7	noise	Estimate of noise sigma, cm^{-3}		
8	d+.42-.56	Size fraction concentration, cm–3	+	0.42−0.56
9	d+.56-.75	Size fraction concentration, cm–3	+	0.56−0.75
10	d+.75-1.0	Size fraction concentration, cm–3	+	0.75−1.00
11	d+1.0-1.3	Size fraction concentration, cm–3	+	1.00−1.33
12	d+1.3-1.8	Size fraction concentration, cm–3	+	1.33−1.78
13	d+1.8-2.4	Size fraction concentration, cm–3	+	1.78−2.37
14	d+2.4-3.2	Size fraction concentration, cm–3	+	2.37−3.16
15	d+3.2-4.3	Size fraction concentration, cm–3	+	3.16−4.22
16	d+4.3-5.6	Size fraction concentration, cm–3	+	4.22−5.62
17	d+5.6-7.5	Size fraction concentration, cm–3	+	5.62−7.50
18	d−.42-.56	Size fraction concentration, cm–3	−	0.42−0.56
19	d−.56-.75	Size fraction concentration, cm–3	−	0.56−0.75
20	d−.75-1.0	Size fraction concentration, cm–3	−	0.75−1.00
21	d−1.0-1.3	Size fraction concentration, cm–3	−	1.00−1.33
22	d−1.3-1.8	Size fraction concentration, cm–3	−	1.33−1.78
23	d−1.8-2.4	Size fraction concentration, cm–3	−	1.78−2.37
24	d−2.4-3.2	Size fraction concentration, cm–3	−	2.37−3.16
25	d−3.2-4.3	Size fraction concentration, cm–3	−	3.16−4.22
26	d−4.3-5.6	Size fraction concentration, cm–3	−	4.22−5.62
27	d−5.6-7.5	Size fraction concentration, cm–3	−	5.62−7.50
28	z+.03-.04	Mobility fraction concentration, cm^{-3}	+	0.032–0.042
29	z+.04-.06	Mobility fraction concentration, cm^{-3}	+	0.042–0.056
30	z+.06-.08	Mobility fraction concentration, cm^{-3}	+	0.056–0.075
31	z+.08-.10	Mobility fraction concentration, cm^{-3}	+	0.075–0.100
32	z+.10-.13	Mobility fraction concentration, cm^{-3}	+	0.100–0.133
33	z+.13-.18	Mobility fraction concentration, cm^{-3}	+	0.133–0.178
34	z+.18-.24	Mobility fraction concentration, cm^{-3}	+	0.178–0.237
35	z+.24-.32	Mobility fraction concentration, cm^{-3}	+	0.237–0.316
36	z+.32-.42	Mobility fraction concentration, cm^{-3}	+	0.316–0.422
37	z+.42-.56	Mobility fraction concentration, cm^{-3}	+	0.422–0.562
38	z+.56-.75	Mobility fraction concentration, cm^{-3}	+	0.562–0.750
39	z+.75-1.0	Mobility fraction concentration, cm^{-3}	+	0.750–1.00
40	z+1.0-1.3	Mobility fraction concentration, cm^{-3}	+	1.00–1.33
41	z+1.3-1.8	Mobility fraction concentration, cm^{-3}	+	1.33–1.78
42	z+1.8-2.4	Mobility fraction concentration, cm^{-3}	+	1.78–2.37
43	z+2.4-3.2	Mobility fraction concentration, cm^{-3}	+	2.37–3.16

No	Header	Value	Sign	Range: nm or $cm^2V^{-1}s^{-1}$
44	z–.03-.04	Mobility fraction concentration, cm^{-3}	–	0.032–0.042
45	z–.04-.06	Mobility fraction concentration, cm^{-3}	–	0.042–0.056
46	z–.06-.08	Mobility fraction concentration, cm^{-3}	–	0.056–0.075
47	z–.08-.10	Mobility fraction concentration, cm^{-3}	–	0.075–0.100
48	z–.10-.13	Mobility fraction concentration, cm^{-3}	–	0.100–0.133
49	z–.13-.18	Mobility fraction concentration, cm^{-3}	–	0.133–0.178
50	z–.18-.24	Mobility fraction concentration, cm^{-3}	–	0.178–0.237
51	z–.24-.32	Mobility fraction concentration, cm^{-3}	–	0.237–0.316
52	z–.32-.42	Mobility fraction concentration, cm^{-3}	–	0.316–0.422
53	z–.42-.56	Mobility fraction concentration, cm^{-3}	–	0.422–0.562
54	z–.56-.75	Mobility fraction concentration, cm^{-3}	–	0.562–0.750
55	z–.75-1.0	Mobility fraction concentration, cm^{-3}	–	0.750–1.00
56	z–1.0-1.3	Mobility fraction concentration, cm^{-3}	–	1.00–1.33
57	z–1.3-1.8	Mobility fraction concentration, cm^{-3}	–	1.33–1.78
58	z–1.8-2.4	Mobility fraction concentration, cm^{-3}	–	1.78–2.37
59	z–2.4-3.2	Mobility fraction concentration, cm^{-3}	–	2.37–3.16
60	power	Power voltage, V		
61	filter	Filter voltage, V		
62	flowrate	Flow rate, dm^3/s		
63	scans	Number of scans in the cycle		
64	balance	Balance control 0...15		

Comments:

1. The filters of two condensers have different voltages. The voltage is presented in column 61 only for this filter, which absolute voltage is lower. The sign of the voltage helps to identify the condenser: − in case of the left and + in case of the right condenser.

2. In the noise check regime, the number of scans is written with the minus sign, which makes possible identifying of the regime.

3. One size or mobility decade contains just 8 logarithmically divided fractions. The values of the distribution function d*n* / d(log *d*), corresponding to the geometric centers of the intervals, are estimated by multiplying the fraction concentrations to the factor of 8. The sequence of 10 geometric centers of 10 fractions is:

0.49 0.65 0.87 1.15 1.54 2.05 2.74 3.65 4.87 6.50

4. The structure of the 2Eyymmdd.xl files saved by BSMA1 and BSMA2 is similar and the first 60 columns contain the same data. The last 4 columns contain different data. In case of BSMA2:

61	filter	Filter voltage (for − ions), V	+	
62	filter	Filter voltage (for + ions), V	–	
63	scans	Number of scans in the cycle		
64	balance	Autobalance potentiometer, %		

In BSMA1 output saved by the control program BSMA2E1 the columns 62 and 63 contain zero values, because the filter voltages are not measured in BSMA1. In 2Eyymmdd.xl files created by conversion of BSMA1 old BSyymmdd.xl files the estimate of noise in column 7 is proportional but not equal to the real noise sigma and column 63 shows the number of 3-minute cycles used when calculating 15-minute average values included into the current line of the file.

7.3. Structure of the additional tables

A diagram table corresponds to one day and contains 10 lines and 145 or 97 columns of tab-delimited numerical values. The diurnal data for positive and negative particles are saved separately in two files pYYMMDD.XL and nYYMMDD.XL. The tables have no headers, the lines correspond to the 10 size fractions and contain diurnal time series of the particle size distribution function d*n* / d(log *d*), where log means the decimal logarithm. The missing data are replaced by zeroes with one exception: gaps up to five cycles inside a day data series are filled with the interpolated data.

In case of 10-minute cycles the first 144 columns and in case of 15-minute cycles the first 96 columns correspond to the beginnings of the cycles. The last column of the table corresponds to the end of the last cycle. The value of the smoothing grade in the tables, which are saved immediately by the control program, is always 1. The smoothing grade is explained in the next section of the manual.

A table of scan details has no general header line and consists of blocks corresponding to measuring cycles. A block consists of *nscan* + 1 data lines, where *nscan* is the number of scans in the cycle. The first line of a block consists of 9 numbers, where the first seven are the same as in the beginning of a line of the main data table:

1) YYMMDD, 2) HHMM, 3) DAY, 4) T, 5) RH, 6) p, 7) noise, 8) balance, 9) nscan.

Each of the following *nscan* lines consists of 16 values, which are the same as displayed in the lower central part of the computer screen during the measurement. The total count of numbers in a block is 9 + 16×*nscan*.

7.4. Creating of contour plots using MATLAB

Contour plots can be easily created by means of a MATLAB function BSMA2PLT.M. This operation cannot be performed on the measurement computer because MATLAB does not run under DOS. The plot files pYYMMDD.XL and nYYMMDD.XL should be copied into the computer where MATLAB is installed. The function processes automatically all diagram table files from the folder indicated by the *filepath*, which correspond to the indicated in BSMA2PLT year and month, and are inside of the indicated interval of days. The results are saved in the same folder and are named *prefix*YYMMDD.JPG, where *prefix* is a text presented in BSMA2PLT. One picture contains diagrams for both polarities and the size of a picture file is about 200-300 kilobytes.

Before launching BSMA2PLT.M should be edited because the information about the file locations is written immediately into the function code. The text of the function is presented below and it can be copied via clipboard into the MATLAB window. The fragments to be edited are marked with an extra bold font.

```
function BSMA2PLT; %HT20050929, minor modification 20061115
% Diurnal contour plots from BSMA2E1, BSMA2E2 or BSMA3A plot tables
% All days of one month in one folder are processed in one session
% Input filenames must be pYYMMDD.xl and nYYMMDD.xl
% Output filenames are [prefix YYMMDD.jpg]

% Permanent sample of information lines:
% prefix = '3A'; % for output file name
%filepath = 'C:\BSMA\plot\'; % where the files are located
%    yymm = '0610'; % year and month
%for  day = 1:31 % interval of days

% The input data, which can be modified following the permanent sample above:
  prefix = '3A'; % for output file name, can be modified
filepath = 'C:\BSMA\PLOT\'; % where the files are located, can be modified
```

```
    yymm = '0610'; % year and month, can be modified
for  day = 1:31 % interval of days, can be restricted

  dd = num2str (day);
  if day < 10
    dd = ['0' dd];
  end;
  if exist ([filepath 'p' yymm dd '.xl'], 'file')
    x = load([filepath 'p' yymm dd '.xl']);
    p = size (x);
    colormap(hsv);
    axes ('units', 'pixels', 'position', [50 320 700 200]);
    [c,h] = contourf (x,
          [100 200 300 400 600 800 1000 1200 1400 1600 1800 2000 2500 3000]);
    brighten (0.6);
    clabel (c,h);
    set (gca, 'xtick', [1:(p(2)-1)/8:p(2)], 'xticklabel', [0:3:24]);
    set (gca, 'ytick', [1 2.18 3.43 4.85 6.65 8.3 10]);
    set (gca, 'yticklabel', {'0.5';'0.7';'1.0';'1.5';'2.5';'4.0';'6.5'});
    %xlabel('Hour'); %could be added
    ylabel('Diameter : nm');
    title(['BSMA2 + ions 20' yymm dd ' dN/dlog(d)']);
    print ('-djpeg', [filepath prefix yymm dd '.jpg'])
    x = load([filepath 'n' yymm dd '.xl']);
    axes ('units', 'pixels', 'position', [50 60 700 200]);
    [c,h] = contourf (x,
          [100 200 300 400 600 800 1000 1200 1400 1600 1800 2000 2500 3000]);
    brighten (0.6);
    clabel (c,h);
    set (gca, 'xtick', [1:(p(2)-1)/8:p(2)], 'xticklabel', [0:3:24]);
    set (gca, 'ytick', [1 2.18 3.43 4.85 6.65 8.3 10]);
    set (gca, 'yticklabel', {'0.5';'0.7';'1.0';'1.5';'2.5';'4.0';'6.5'});
    xlabel('Hour');
    ylabel('Diameter : nm');
    title(['BSMA2 - ions 20' yymm dd ' dN/dlog(d)']);
    print ('-djpeg', [filepath prefix yymm dd '.jpg'])
    close all;
  end; %of if exist
end; %of days
```

If the diagram tables were not saved during the measurement, then these tables can be generated from the main data table by means of a special program DIATAB.EXE. If the computer is running under WINDOWS, then the icon of the main data table should be dragged onto the icon of the DIATAB.EXE. As a result, the diagram tables are saved into the same folder, where the main data table is located. Before data processing, the program asks for the smoothing grade, which should be presented with a whole number 0...5. Zero marks no smoothing and a nonzero grade N means that the data will be smoothed calculating repeatedly N times the averages over the neighbor triples: $x_i := (x_{i-1} + 2\, x_i + x_{i+1}) / 4$. The smoothing suppresses the noise but reduces the time resolution. In a typical situation, a weak smoothing of grade 1 is recommended. The tables, which are saved immediately by the measurement program, are always smoothed with grade 1.

An example demonstrating the effect of smoothing is presented in Figure 7.1.

7.5. Computing of hourly averages

The files of hourly averages can be compiled by means of the program HOURTAB.EXE. A file of hourly averages contains one data line for every hour; everything is the same as in the main table. The time in the second column is written for the middle moment of the hour as HH30. The program HOURTAB.EXE should be launched just as the program DIATAB.EXE by dragging the icon of a main data table onto the icon of the program. If the source file is 3AYYMMDD.XL then the result will be named 3HYYMMDD.XL, only the second character in the file name is changed. A hourly time series in the main data table consists of one value for every cycle, which makes altogether 4 or 6 values. The program HOURTAB.EXE discriminates extreme values: the smallest and the largest value in an hourly series are ignored and the arithmetic average is calculated from the remaining values. An hour, which is presented with less than three measurements, is skipped in the resulting table.

7.6. Examples

The measurements presented below are carried out using BSMA2, which output data is compatible with the output data of BSMA3.

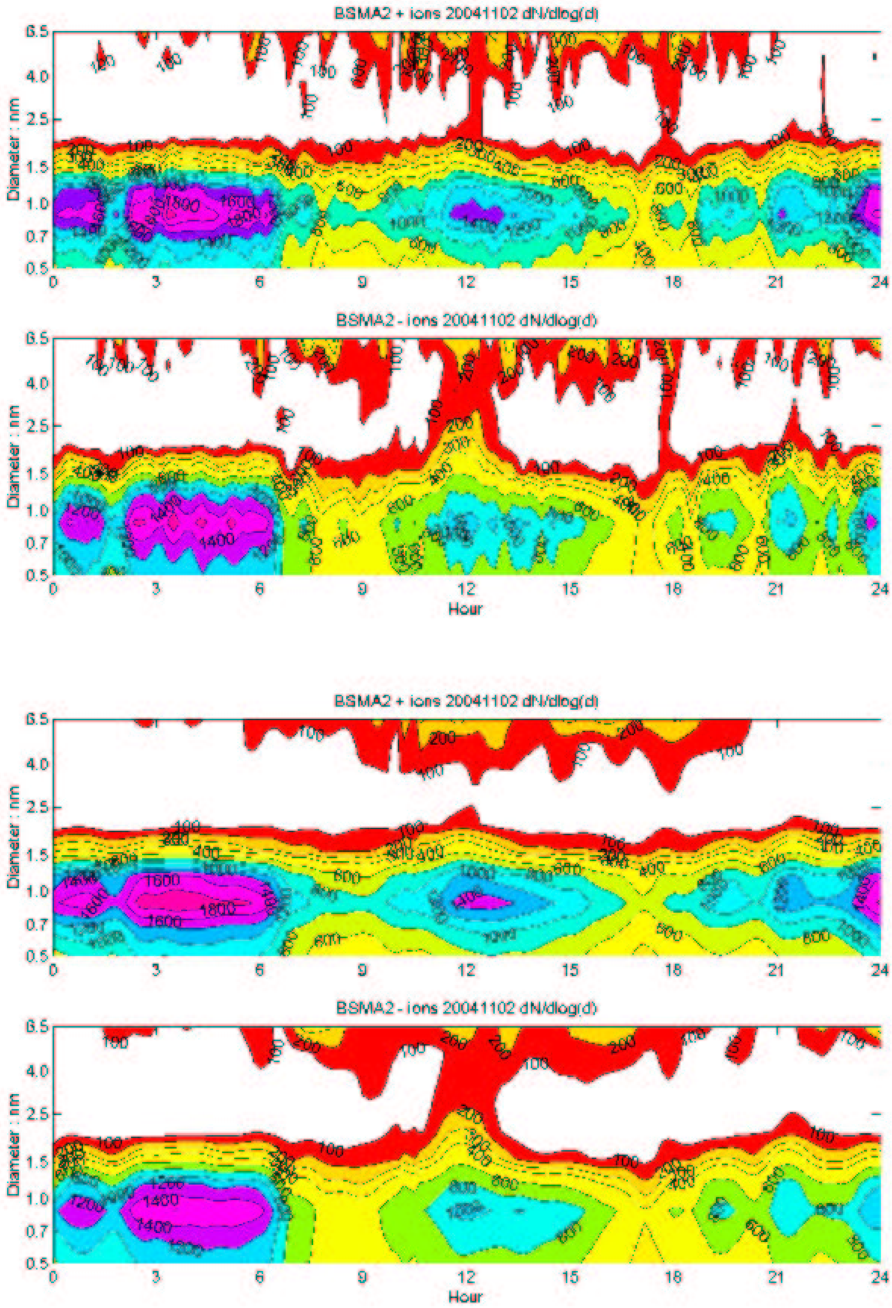


Figure 7.1. The diagrams smoothed with grade = 0 (upper picture) and with grade 5 (lower picture).

Example of color diagrams Figure 7.1 illustrates the result of the MATLAB function BSMA2PLT.M and the effect of smoothing the diurnal data series by the program DIATAB.EXE

Figure 7.2 shows the ion mobility distribution in the laboratory air during an experiment demonstrating the balloelectric effect. A thin water jet hits a ceramic wall imitating the conditions of heavy rain. The splashing of water generates a number of negative ions of the mobility below 1 cm^{2}V^{-1}s^{-1}, which corresponds to the particle size over 1 nm. The positively charged particles are created probably as a result of neutralization and the following diffusion charging of the initially negative particles.

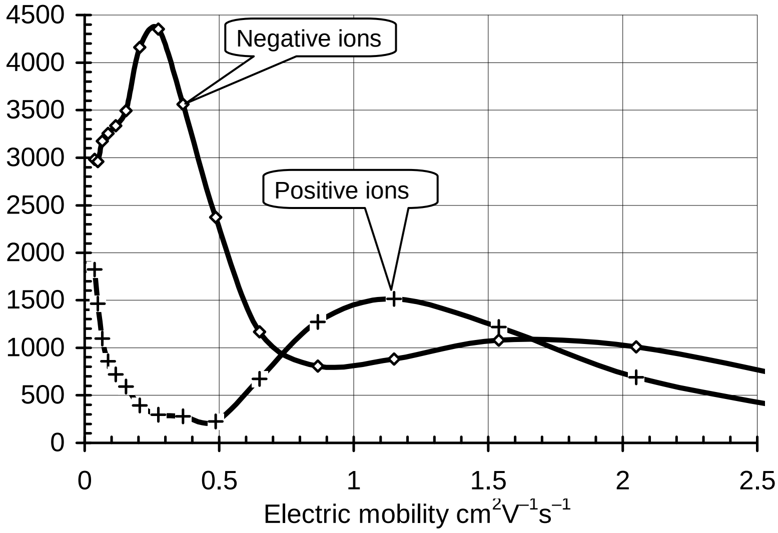


Figure 7.2. Mobility distribution of ions measured using BSMA2 during the experimental checking of the balloelectric effect.

The effect of the natural rain is shown in Figure 7.3 as recorded by the BSMA2 during routine measurements in the city of Tartu, Estonia. The diagrams illustrate the result of MATLAB function BSMA2PLT.M in a grayscale presentation.

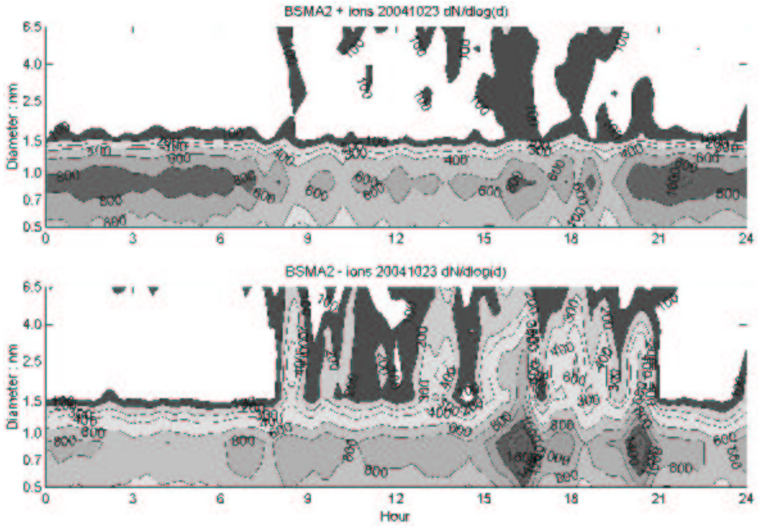


Figure 7.3. Evolution of size distribution of charged particles in the urban air during a heavy rain.

The diagram in Figure 7.3 is similar to the contour plots of nucleation bursts. The peculiarity is that only the negative nanometer particles were generated. The generation of particles is strongly correlated with the rain intensity and ceases when the rain stops.

8. MAINTENANCE OF THE INSTRUMENT

8.1. Installing of BSMA3

BSMA3 package consists of

1. Main unit of BSMA3.
2. 24 V power supply Mascot 2020.
3. PICO ADC-16.
4. Triple-connector data cable.
5. Serial cable for ADC-16.
6. Manual and software listings.
7. CD with documentation and software.
8. Two floppy disks with software.

The main unit of the BSMA3 is shown in Figure 8.1. The normal position of the instrument is with horizontal airflow. On this occasion the height of the instrument with handles is 36 cm, the width is 32 cm and the length along the air flow is 44 cm. Some additional space is needed for a recording computer. Any IMB PC compatible computer that recognizes instructions for numerical processor (e.g. 486DX and higher) and can run under MS DOS is suitable for controlling the measurement and recording the data.

The air is sucked in through two openings of 240 (height) × 58 (width) mm in the front end of the instrument (see Figure 8.1). The width of the two inlet openings together with the separating part of the front panel is 158 mm. The air flows out from a round opening of the diameter of 220 mm in the rear end. The internal pressure drop generated by the fan is about 200 Pa. This is not a high value and the instrument is slightly sensitive to wind. The external wind velocity difference of 5 m/s between the inlet and the outlet of the instrument will generate an extra pressure of about 15 Pa that results in a 4% change of the internal air flow velocity. It is recommended to install the instrument for stationary measurements in such a way that the air will flow out from the same side of the building as the inlet (see draft in Figure 8.2 and example in Figure 8.3). The cross section of the external air channel should be at least 4 dm^2.

An alternative possibility is to install the instrument in a vertical position so that the inlet is below and the air will flow vertically upwards.

After the instrument has been positioned the electrical connections have to be made:

- A special triple-connector cable should be connected according to the marks on the connectors with the BSMA3, the ADC-16, and the LPT1 port of the computer.
- The ADC-16 should be connected via a serial cable with the COM1 port of the computer.
- The power supply should be connected with the BSMA3. Warning: the polarity of the Mascot-2020 output plug is convertible. Make sure that the center electrode is positive!
- The ground wire should be connected to the ground socket or to any cover screw of the BSMA3. In case of stationary installation, the latter way is preferred.

The ground connection is required because the electric field around the case of the instrument can disturb the admission of ions and charged particles into the inlet of the instrument. The BSMA3 is relatively insensitive to weak external electric fields due to the high ventilation rates.

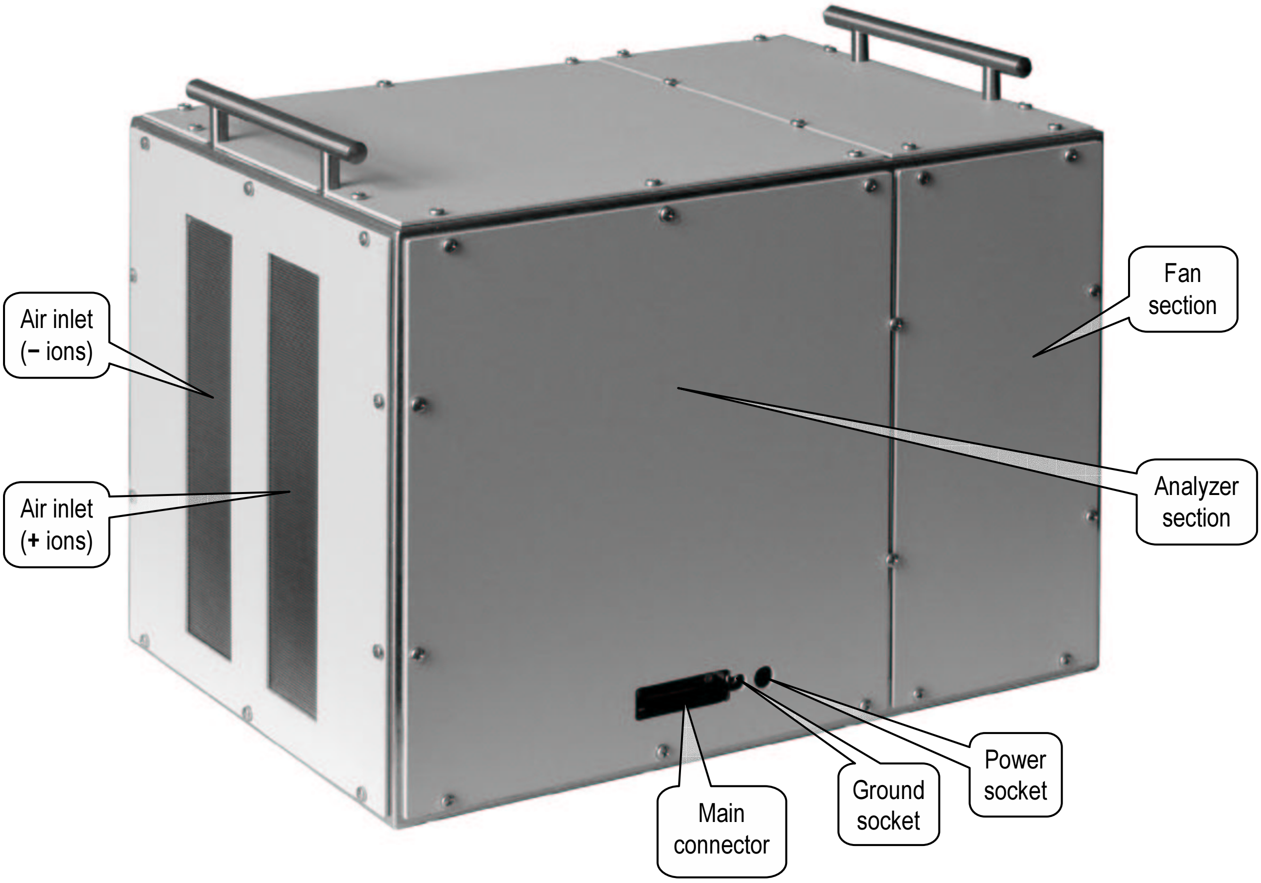


Figure 8.1. Main unit of the BSMA3.

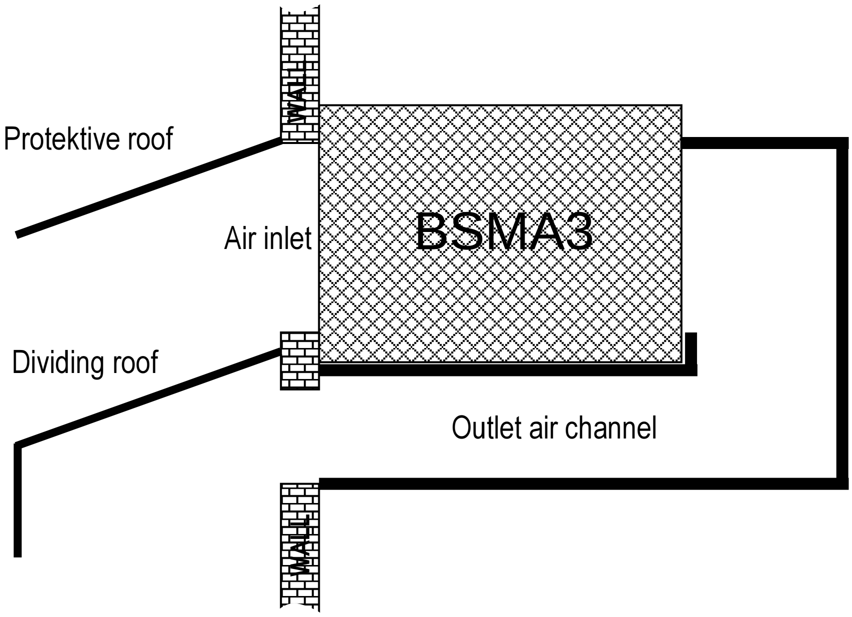


Figure 8.2. Installation of the BSMA3 insensitive to wind.

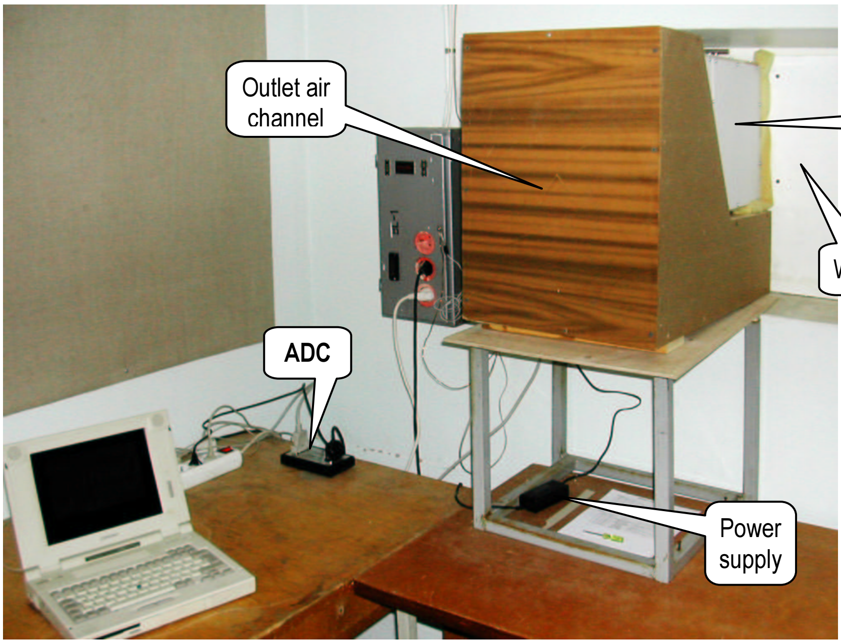


Figure 8.3. BSMA3 installed for routine measurements.

The PICO ADC-16 is sensitive to electromagnetic interference. Thus it should be placed on a grounded surface and fixed in a stable position so that any cable will not cross the ADC. The possible interference noise should be tested running the control program BSMA3A. The test regime "T" is to be chosen from the start menu (Figure 6.1) and the key "R" should be pressed for a test. The computer displays 25 times the readings of all ADC channels after single pressing the R-key. ADC1 is the BSMA3 control zero and the reading of this channel must permanently be zero. If there are several non-zero readings or any reading exceeds 1, then the location of ADC and connecting cables must be adjusted until ADC1 will permanently show zero in the test measurement.

Warning: *PICO ADC-16 has no locking nuts to fix the 25-pin connector. Thus the cable must be firmly fixed to some support near the ADC.*

8.2. Preparing the control computer

The control program BSMA3A should run under MS DOS. The computer must have a floating-point processor (a 486 processor must be with suffix DX). Launching the measurements is convenient when the computer is specially prepared.

The booting sequence of the specially prepared computer should be C: A:. The root folder of the computer should contain a folder BSMA and a brief file BSMA.BAT, which content is:

```
PATH=C:\BSMA;C:\BSMA\TOOLS
CD \BSMA
BSMA3A.EXE
NC
```

The last command of AUTOEXEC.BAT should be

```
CALL BSMA.BAT
```

The mouse driver should not be active. Corresponding lines in autoexec.bat and config.sys could be blocked using REM prefix.

The folder BSMA should contain at least two files

```
BSMA3A.EXE      BSMA3A.INI
```

and five subfolders:

```
MONTHS   DAYS   TABLES   DETAILS   TOOLS
```

Four first folders remain empty at the installation time.

The subfolder TOOLS should consist at least of 11 files:

```
NC.CFG  NC.EXE  NC.EXT  NC.HLP  NC.INI   NC.MNU
NCEDIT.EXE  NCMAIN.EXE  NCZIP.EXE
PACKER.EXE  PACKER.SET
```

When running, the program BSMA3A automatically creates two additional files BSMA3.DFL and TIMING.LOG in the folder BSMA.

The program `BSMA3A.EXE` can be compiled on another computer but the most reliable way is to compile it on the same computer, which is used for the control of the BSMA3. In this case the subfolder TOOLS should contain 3 additional files

```
TURBO.EXE   TURBO.TP    TURBO.TPL
```

and the folder BSMA should contain the source code

```
BSMA3A.PAS
```

The Turbo Pascal compiler options "286 instructions" and "8087/80287" should be checked. The folder BSMA is to be selected as the active folder and the Turbo Pascal launched writing the command line:

```
\BSMA\TOOLS\TURBO
```

When Turbo is running, BSMA3A.PAS should be opened. Next, the Alt+C is to be pressed and *Destination Disk* selected. After this the function key F9 activates the compiler and BSMA3A.EXE will be compiled and saved in the home folder BSMA.

The versions of BSMA3A.EXE compiled in different computers may have different timing parameters. Thus the time calibration file BSMA3.DLF should be renovated when BSMA3A.EXE is imported from another computer.

8.3. Using the control program on an unprepared computer

BSMA3A can be used in any PC-compatible computer, which has free LPT1 and COM1 ports, and MS-DOS, Windows 95 or Windows 98 operating system. Windows NT, Windows 2000 and Windows XP cannot be used because they do not allow direct access of the ports. If the computer has Windows operating system, then the program will not automatically restart after a blackout of power. Thus, the preferred operating system is still MS DOS.

If Windows is installed in the computer, then the computer must be booted in the DOS regime, because the timing would be inexact when running in a window. The DOS regime can be selected when the key F8 is pressed during the booting process. If the key F8 was missed and the computer has already entered the Windows regime, then it should be restarted in the DOS regime.

BSMA3A.EXE can be located in any folder, which contains at least the obligatory subfolders MONTHS, DAYS, and TABLES. BSMA3A.INI must be written into the same folder as BSMA3A.EXE. The file BSMA3E.DLF must never be copied or written manually, the control computer should create this file itself during the first run of BSMA3A.EXE.

8.4. Routine cleaning of the instrument

Warnings:

- *The instrument contains high voltage circuits. The case of the instrument can be opened only after the power cord has been detached from the instrument for at least 30 s.*
- *The transparent details in the instrument are made of polycarbonate, which is soluble in acetone. Keep acetone and acetone-containing solvents carefully away of the instrument as the insulators can be damaged when contacted with acetone.*
- *The screws should be fixed in polycarbonate with a low moment, the torque should not exceed 0.1 N/m. It is recommended to use a thin-handle screwdriver (diameter up to 10 mm).*

The inlet grid of the BSMA3 collects fine insects, dust and fibers from the air. Dust and fibers adsorb the ions and increased inlet loss of ions disturbs the results of the measuring of fraction concentrations. Thus the grid needs regular cleaning depending on the level of air pollution. In summer the grid usually requires quick cleaning every week and during some periods even every day. In winter, the cleaning period is longer and usually it is enough to clean the grid at the same time as the aspiration condensers are cleaned.

Quick cleaning of the inlet grid is performed by means of a vacuum cleaner without disassembling the instrument and stopping the measurement. The data storage could be switched off (Alt+D) just when beginning the cleaning and on again (Ctrl+D) after the beginning of a new cycle when the cleaning procedure is finished.

Thorough cleaning of the inlet grid is usually performed together with the cleaning of the aspiration condensers. In this case the front panel is detached from the instrument and it could be washed with a detergent and water using a brush. The grid is made of perforated aluminum and should be manipulated with care to avoid deformation.

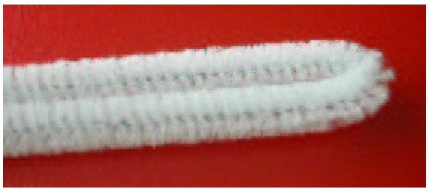


Figure 8.4. Bended brushing wire.

In summer the filter is often polluted by small insects that have passed through the inlet grid and have been trapped in the strong electric field of the filter. The electric resistance of the insects is high and usually they do not overload the filter voltage supply. The filter voltage is continuously monitored and recorded together with the measurements. If the supply is overloaded, then the filter voltage is displayed on the computer screen in blinking red and the measuring process may be interrupted until the next full hour.

The first damage caused by insects is the additional ion adsorption. The insects can be removed using a thin brush wire (see Figure 8.4), available in "Tiimari" shops. For cleaning of the filter, the measuring should be stopped and the front panel of the BSMA3 removed. Brushing loosens the insects from the filter electrodes and they can be finally sucked away by a vacuum cleaner.

When the BSMA3 is disassembled for cleaning the aspiration condensers, the filter can also be fundamentally cleaned using a thin jet of pressurized water.

During routine measuring, the dust and soot are accumulated on the insulators of the aspiration condensers. At first, the lower insulators of the condensers will be polluted. The bridge balance is very sensitive to the leakage of the high voltage insulators and fluctuations of the balance induce noise in the electrometer signal. The first symptom of pollution is enhanced measuring noise in the situation of high humidity. The noise index and relative humidity are indicated on the computer screen and saved into the output files.

Cleaning of the aspiration condensers is possible after partial disassembling of the instrument. The procedure of disassembling is the following. Remove the upper panel of the main section of the instrument. Disconnect four non-insulated wires from the electrometric amplifier (see

Figure 8.7) using tweezers. Warning: *keep one hand in the electric contact with the instrument frame when touching these wires*. Disconnect the output cable from the electrometric amplifier, unscrew four screws and remove the amplifier. Store the amplifier carefully and avoid polluting of its inlet elements. Then turn the BSMA3 upside down and take away the bottom panel of the main section. Take away the black high voltage cables and filter cables from the aspiration condensers. The connectors of heating cables are in a narrow slit between the condensers and they can remain connected because it is easier to disconnect the heating cables from the voltage source. Remember well all connections to be able to assemble the instrument again. Then turn the instrument to the vertical position the fan section down, screw away the front panel with the inlet grid, take a 300 mm long Ph1 screwdriver and unscrew eight M4 screws fixing the condensers to the bottom of the instrument frame. Now the condensers can be carefully removed from the instrument through the front opening of the frame (Figure 8.5).

The insulators of the inner electrode of an aspiration condenser can be cleaned using a thin and long wooden spike with a piece of clean cloth or soft paper fixed to one end. The best cleaning liquid is the deionized water. For preliminary cleaning of very dirty surfaces, use the clean ethyl alcohol or the water with admixture of a detergent. After using of cleaning liquids other than clean water the insulators must be properly rinsed, first with the tap water and then at last twice with the deionized water. Blow away the water droplets from the insulators after every rinsing using the outlet jet of a vacuum cleaner or clean pressurized air. Use the spray of deionized water for the final rinse and dry the details properly before assembling the instrument.

For the cleaning of the collector and electrometric insulators the collector panel should be detached from the condenser. Screw off 14 M3×8 (do not use long screws when reassembling!) screws and detach the panel (see Figure 8.6). The collector is fixed on two yellow cylindrical polyether imide insulators. These insulators can be first cleaned with clean ethyl alcohol and finally with a spray of deionized water.

Thorough cleaning of the high voltage insulators is easier when one or both side panels of a condenser are removed. The unit composed of the internal electrode of the condenser, two polycarbonate insulators, and the filter stack, should never be disassembled. During the thorough cleaning, the aluminum surfaces should be cleaned using a soft paper wetted with ethyl alcohol.

Warning: *avoid carefully any deformation of the side panels of condensers*. A small change in the distance between plates does not have significant effect on the measured concentrations and mobilities, but it can notably shift the balance of the bridge.

Notice the marks on the parts when assembling the instrument. The aspiration condensers should be installed and fixed with screws when the instrument is in vertical position like in Figure 8.5. Warning: *do not forget to connect the electrometer input wires and the cables of the heating resistors to the condensers before putting them back into the frame.*

The both heating resistors can be switched to 15 V (recommended) or 24 V sockets, but never to different voltages. See Figure 8.8.

The electrometer unit should be reinstalled last. Use tweezers to connect the wires and keep one hand in contact with the electrometer frame. The connections of the electrometer are shown in Figure 8.7.

The correct connections below the aspiration condensers are shown in Figure 8.8.

Warning: *the wide border of a front panel must be above the inlet grids when reassembling the case of the instrument.*

Figure. 8.5. Removing of an aspiration condenser from BSMA3.

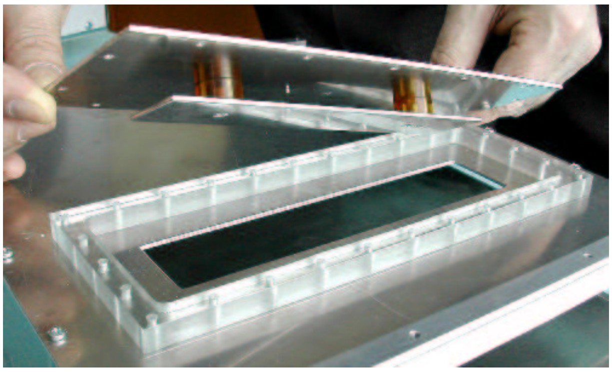


Figure. 8.6.
Detaching of a collector panel.

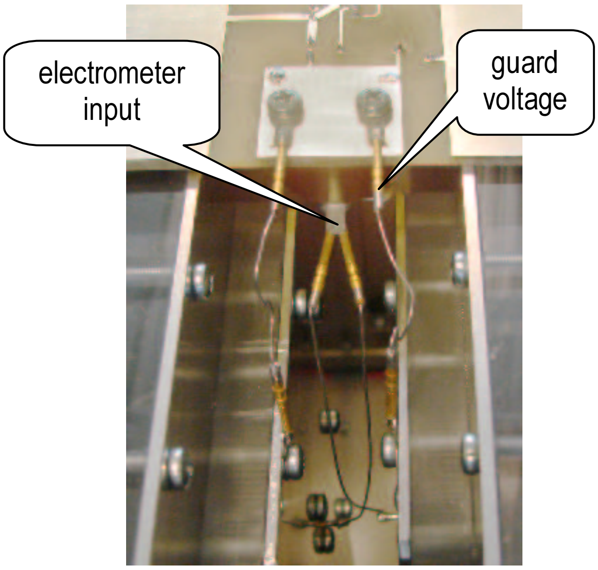


Figure 8.7.
Input connections of an electrometer.

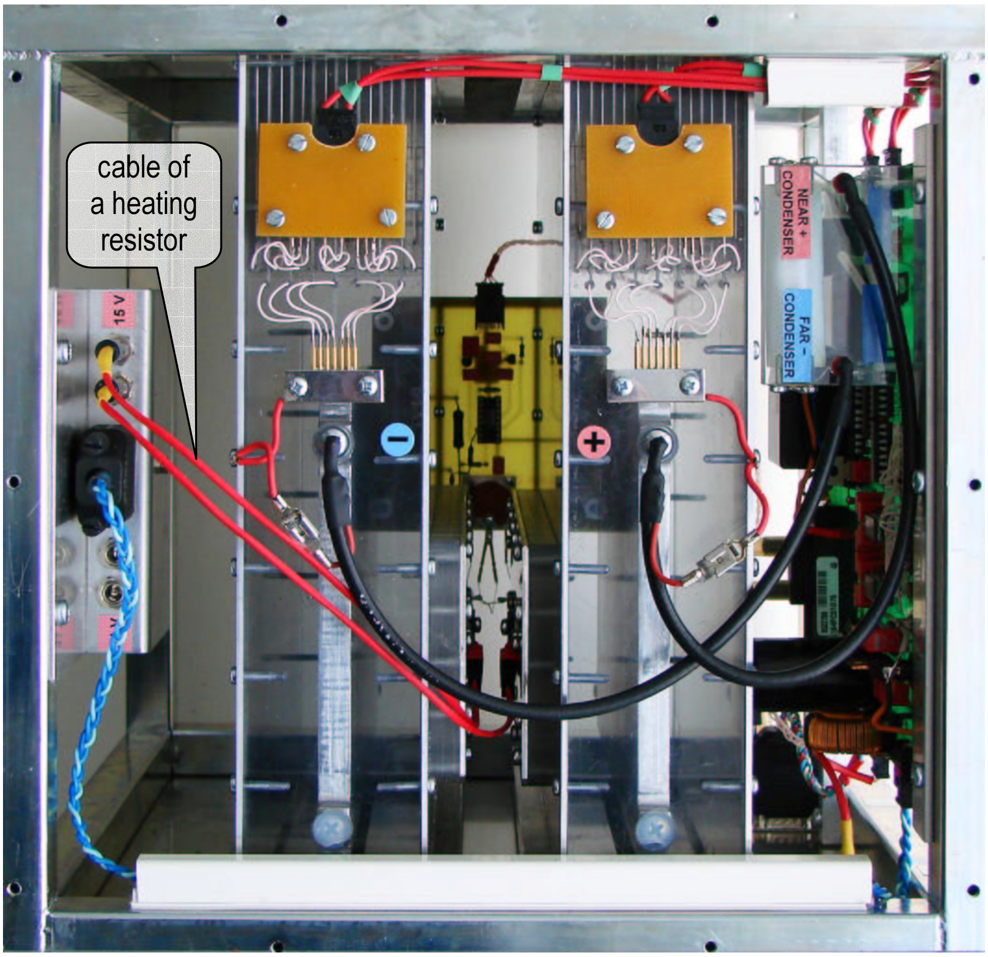


Figure 8.8. Connections below the aspiration condensers.

8.5. Simple diagnostics of the hardware problems

The information necessary for the simple diagnostics is displayed on the computer screen during the routine measurement. A severe corruption of the regime is marked by blinking red of the critical numbers. The most probable disturbances are:

- pollution of the inlet grid with fibers and fuzz,
- pollution of the internal surfaces of insulators of the high voltage electrodes of analyzers,
- pollution of the filters with fuzz and tiny insects,
- pollution of the insulators of the collector electrode.

The fibers and flakes adsorb the ions and decrease the recorded values of the ion concentration especially in the region of small ions; adsorption is proportional to the mobility in the power of 2/3. However, slight pollution cannot be identified according to the displayed fraction concentrations because there is no information about adsorption-free measurements. Thus, the regular visual inspection of the inlet grid is necessary.

Pollution of the insulators of high voltage electrodes leads to the fluctuations of the bridge balance because the resistance of a polluted surface of the insulator is usually strongly fluctuating. This results in increased measurement noise especially in the conditions of high air humidity. When the insulators are clean, the displayed values of the noise index in outdoor measurements remains below 10 even at the relative humidity of 99%. Cleaning is recommended when the noise index systematically exceeds 10.

Pollution of inlet filter insulators can be identified according to the displayed filter voltages. The absolute values of these voltages should both be about 500V. The filters require immediate cleaning when any of the filter voltages drops below of 450 V. The experience of routine measurements has proved that usually is enough to clean the filters during regular cleaning of aspiration condensers.

The pollution of the insulators of the collector electrodes is indicated by the measurement noise, which does not depend on the mobility and cannot be reduced by the cleaning of the insulation of the HV electrode. The experience of exploitation of the BSMA2 showed that the cleaning of insulators of the collector electrodes is required only once per year of routine measurements.

Fluctuations in the electrometer signal, which appear as the measurement noise, have several simultaneous origins. The effect of fluctuations of the bridge balance is proportional to the voltage, which decreases quickly during a scan. The bridge noise has only 1–10% of its initial value in the region of cluster ions. In case of polluted insulators and high humidity the data on the nanometer particles are often corrupted with noise, but the cluster ion data are still usable. Another important component of noise is produced by the alpha rays emitted by the daughter elements of radon. Most essential are ^{218}Po ($t_{1/2}$ = 182 s), ^{214}Pb ($t_{1/2}$ = 1620 s), and ^{214}Bi ($t_{1/2}$ = 1190 s), which are presented in the air with about equal activities. They are carried by air ions and aerosol particles, which are deposited onto the electrodes of the aspiration condenser. One alpha particle generates about 100000 ion pairs. These ions, when attracted to the collector, produce a noise pulse. This component of noise cannot be eliminated by cleaning the instrument, because the electric field in the condensers continuously collects the radioactive ions and aerosol particles. The radioactive pollution on the electrodes will decay itself during a few hours when the radon concentration in the air is returned to a low level.

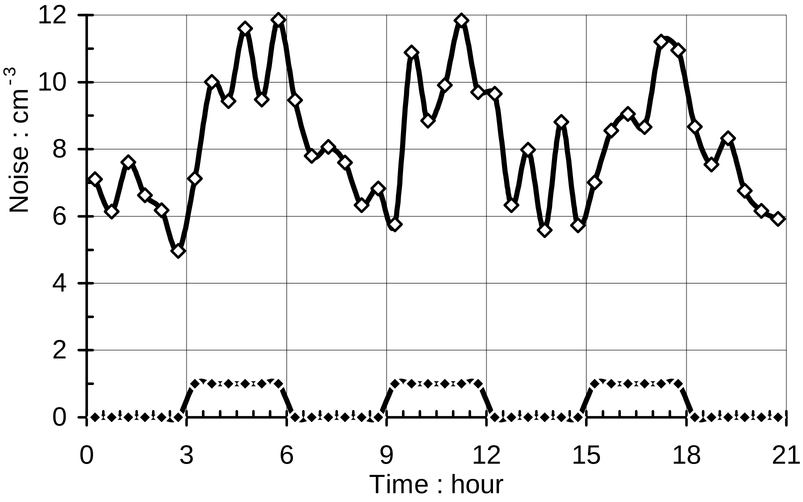


Figure 8.9. Noise of the BSMA3 during periodical commutation of the air flow. Lower curve shows the regime: 0 = fan is switched off, 1 = normal air flow. Upper curve shows the standard deviation of the BSMA3 readings on the scale of air ion fraction concentrations.

The effect of the accumulation of radioactivity in the aspiration condensers is demonstrated in Figure 8.9. The experiment was provided in a laboratory. When the fan is switched off the radioactive deposit decays and noise approaches the value of about 5 cm^{-3}, which is characteristic for a clean instrument in the low-radon air. During the periods of ventilation the radioactive deposit is accumulated again and noise approaches a level of above 10 cm^{-3}, which is characteristic for closed rooms with a relatively high concentration of radon.

8.6. Advanced diagnostics of the hardware problems

The bridge balance is automatically adjusted in the range of 0–15. If the balance is set to an extreme value 0 or 15, then this number is indicated in blinking red. The manual correction of balance should be made when the balance index has an extreme value and the first numbers indicated during a scan in the middle bottom section of the computer screen are systematically outside of the range –3000...+3000. The balance can be corrected replacing the balance adjustment resistor, which is installed in a socket placed on the PC board as shown in Figure 8.10. The replacement resistor is calculated having in view that one step of the automatic balance correction corresponds to 75 kΩ change in the composite resistance R_b × 2000 kΩ / (R_b + 2000 kΩ). The bits of the balance index switch off the resistors in the other arm of the bridge. Thus the balance adjusting resistor should be decreased for increase in the balance index.. The value of the new balance resistor must be inscribed into the file BSMA3A.INI.

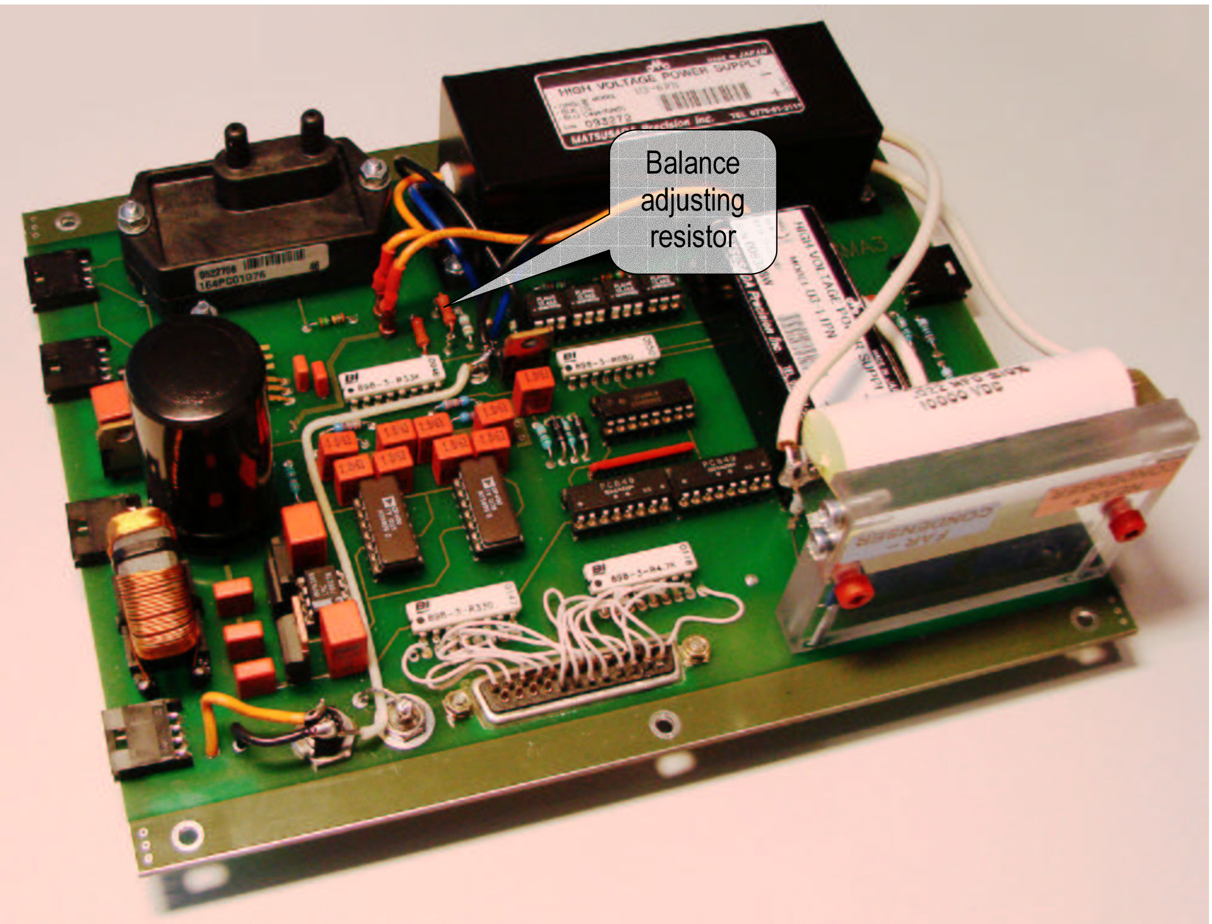
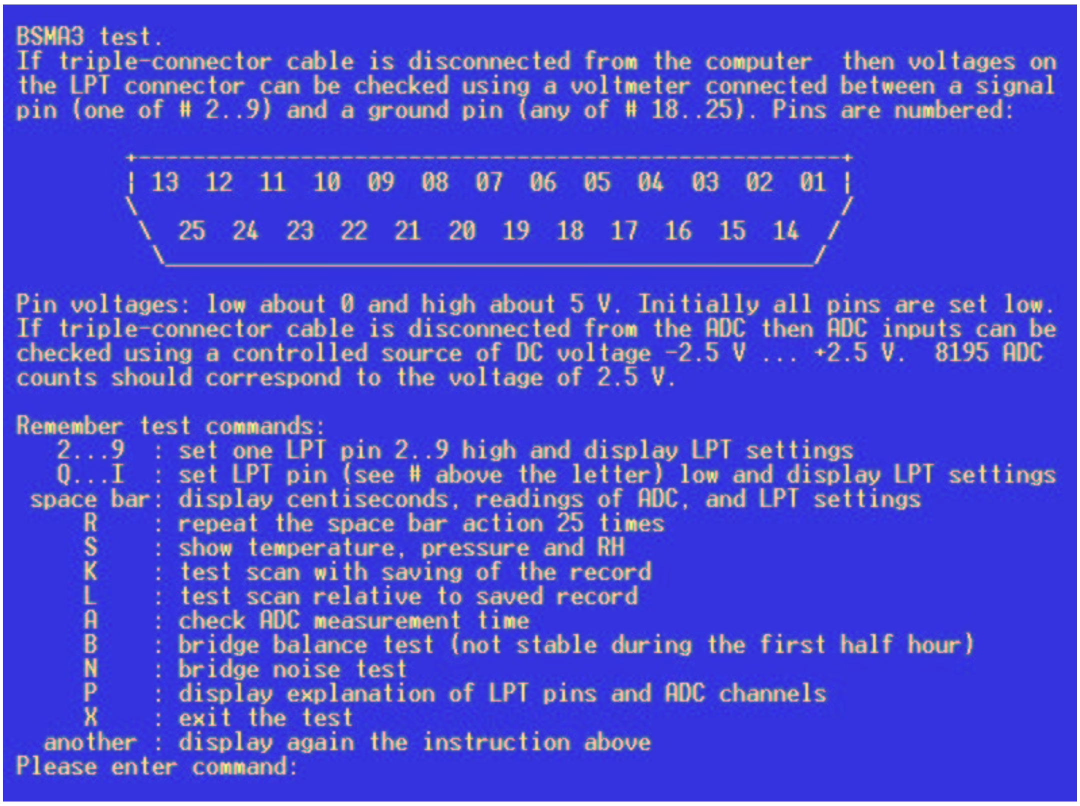


Figure 8.10. Main PC board of the BSMA3.

The electrometer bias is displayed on the computer screen during the routine measurements. The range of the allowed bias of the electrometric amplifier INA116 is −5...+5 mV. The amplifier is recommended to be replaced, if the bias is out of this range.

The range of the allowed power voltage is 22...25 V. If the voltage display on the computer screen is out of this range, then the power circuit should be inspected using a voltmeter. When replacing the power source, the Mascot 2020 or ZVC65SG24 can be considered as proper power units.

The program BSMA3A contains a special test block, which can be launched from the start menu shown in Figure 6.1. The advanced diagnostics expects detailed knowledge of the hardware of the BSMA. The test block displays the menu shown in Figure 8.11.



```
BSMA3 test.
If triple-connector cable is disconnected from the computer  then voltages on
the LPT connector can be checked using a voltmeter connected between a signal
pin (one of # 2..9) and a ground pin (any of # 18..25). Pins are numbered:

        +-----------------------------------------------------+
        | 13  12  11  10  09  08  07  06  05  04  03  02  01  |
        \                                                     /
         \  25  24  23  22  21  20  19  18  17  16  15  14   /
          \_________________________________________________/

Pin voltages: low about 0 and high about 5 V. Initially all pins are set low.
If triple-connector cable is disconnected from the ADC then ADC inputs can be
checked using a controlled source of DC voltage -2.5 V ... +2.5 V.  8195 ADC
counts should correspond to the voltage of 2.5 V.

Remember test commands:
   2...9  : set one LPT pin 2..9 high and display LPT settings
   Q...I  : set LPT pin (see # above the letter) low and display LPT settings
 space bar: display centiseconds, readings of ADC, and LPT settings
     R    : repeat the space bar action 25 times
     S    : show temperature, pressure and RH
     K    : test scan with saving of the record
     L    : test scan relative to saved record
     A    : check ADC measurement time
     B    : bridge balance test (not stable during the first half hour)
     N    : bridge noise test
     P    : display explanation of LPT pins and ADC channels
     X    : exit the test
  another : display again the instruction above
Please enter command:
```

Figure 8.11. Menu of the diagnostic tests.

Numerical commands allow switching single bits of the control port, and space bar displays the ADC readings from all signal channels. The control bits and signal channels are explained in Tables 8.1 and 8.2.

Table 8.1.

Connector pins and control bits of BSMA3

LPT pin	BSMA pin	Port value	Bit	Function
2	18	1	**1**	Fan: 0 = off, 1 = on
3	19	2	**2**	6 kV: 0 = off (scan), 1 = on (charging)
4	20	4	**3**	+ Ion gate: 0 = open, 1 = closed (0V / –250V)
5	21	8	**4**	– Ion gate: 0 = open, 1 = closed (0V / +250V)
6	22	16	**5**	Balance1
7	23	32	**6**	Balance2
8	24	64	**7**	Balance4
9	25	128	**8**	Balance8
21..25	12&13			LPT common (LPT is optoisolated)

The BSMA3 connector pins 11 and 14−17 are not connected. The BSMA frame and case are connected to the signal ground. The left condenser (near the PC boards) collects positive ions: the inner electrode is positive, the filter and gate are negative. The right condenser collects negative ions: the inner electrode is negative, the filter and gate are positive.

Table 8.2.

ADC channels, connector pins and signals of BSMA3

ADC channel	BSMA pin	Function	Approximate transfer coefficients
1	01	Control zero	
2	02	Electrometer	1 pA => 172 mV
3	03	Analyzer voltage	1 : 1280, 3 kV => 2.35 V
4	04	Flow rate	
5	05	Atmospheric pressure	1000 mb => 2 V
6	06	Humidity	0% => 0.4 V, 100% => 2V
7	07	Temperature	100 C => 1 V
8	08	Power&filter voltage	1 : 16.7 & 1 : 655
0	09&10	Signal common	

The output of the ADC is the sign and 13 value bits and the exact measurements are guaranteed in the range of −8191...+8191. The corresponding voltages are −2.5...+2.5 V, and the value of a count is 0.305 mV. The gain of the electrometric amplified can be changed using a replaceable resistor. At the standard value of 1500 Ω of the resistor the gain is 34.3 and a count of the ADC corresponds to 8.885 μV in the electrometer inlet. Actually, the ADC accepts the inlet voltage up to 5 V, but without the warranty of correct conversion.

The ADC channels and voltages on the computer LPT connector can be checked when the triple-connector cable is removed. When a known voltage V in the range of –2.5...2.5 volts is applied to an inlet of the ADC, then the reading must be (8191 / 2.5) × V.

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APPENDICES

Appendix 1. Specifications of the BSMA3

Size: length 44 cm, width 32 cm, height 36 cm.

Mass: 18 kg.

Power: AC 47–63 Hz, 90–260 V, 70 W,

or DC 23-24 V (two car batteries), 60 W.

Suitable power units: Mascot 2020 or ZVC65SG24.

Air flow rate: 39–40 $dm^3 s^{-1}$.

Passage time of air from the inlet grid to the ion collector: 0.1 s.

Heat emission of the electronics inside of the analyzer section: 20 W.

Increase in the air temperature during measurement due to the heat emission: 0.3 K.

Thermal insulation inside of the cover panels: foam polystyrene 10 mm.

Mobility range: 0.032–3.2 $cm^2 V^{-1} s^{-1}$.

Fraction concentration standard range: 0–40000 cm^{-3}, the range can be increased changing the electrometer gain control resistor.

Mobility resolution: 16 mobility fractions.

Electrometric amplifier: INA116.

Humidity of analyzed air in case of unpolluted insulators: up to 99%.

Standard deviation of a fraction concentration in the conditions of simultaneous measurement of two polarities, 10-minute averaging, clean insulators, low radon concentration, moderate humidity, and low wind: about 5 cm^{-3}.

Most essential differences when compared with BSMA1:

The air flow rate is recorded using a differential manometer.

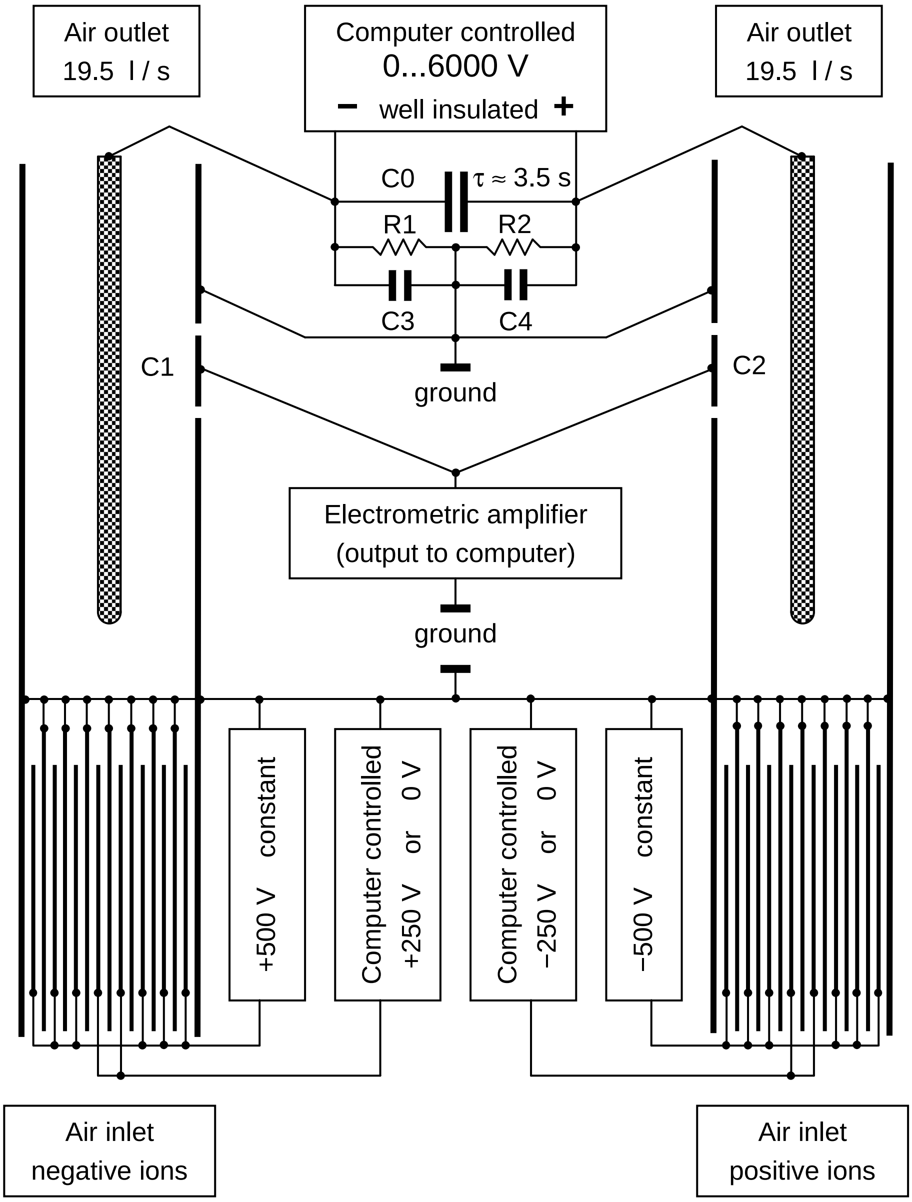
The voltages on the inlet filters and gates are monitored.

The signal of the humidity sensor is corrected according to the air temperature.

The inlet losses of ion are numerically compensated according to an advanced method.

The control program is improved.

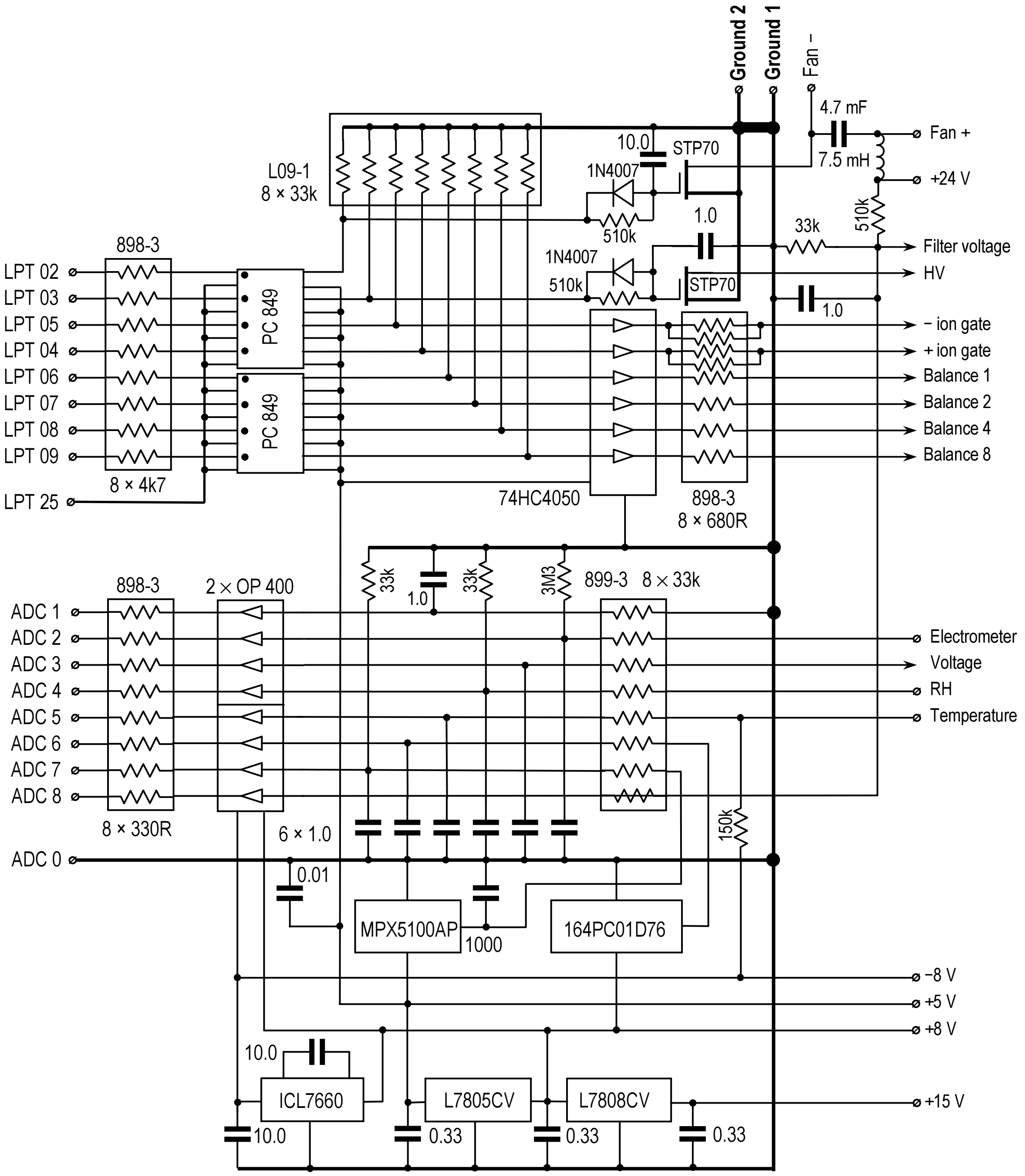
Appendix 2. BSMA3 electric diagrams



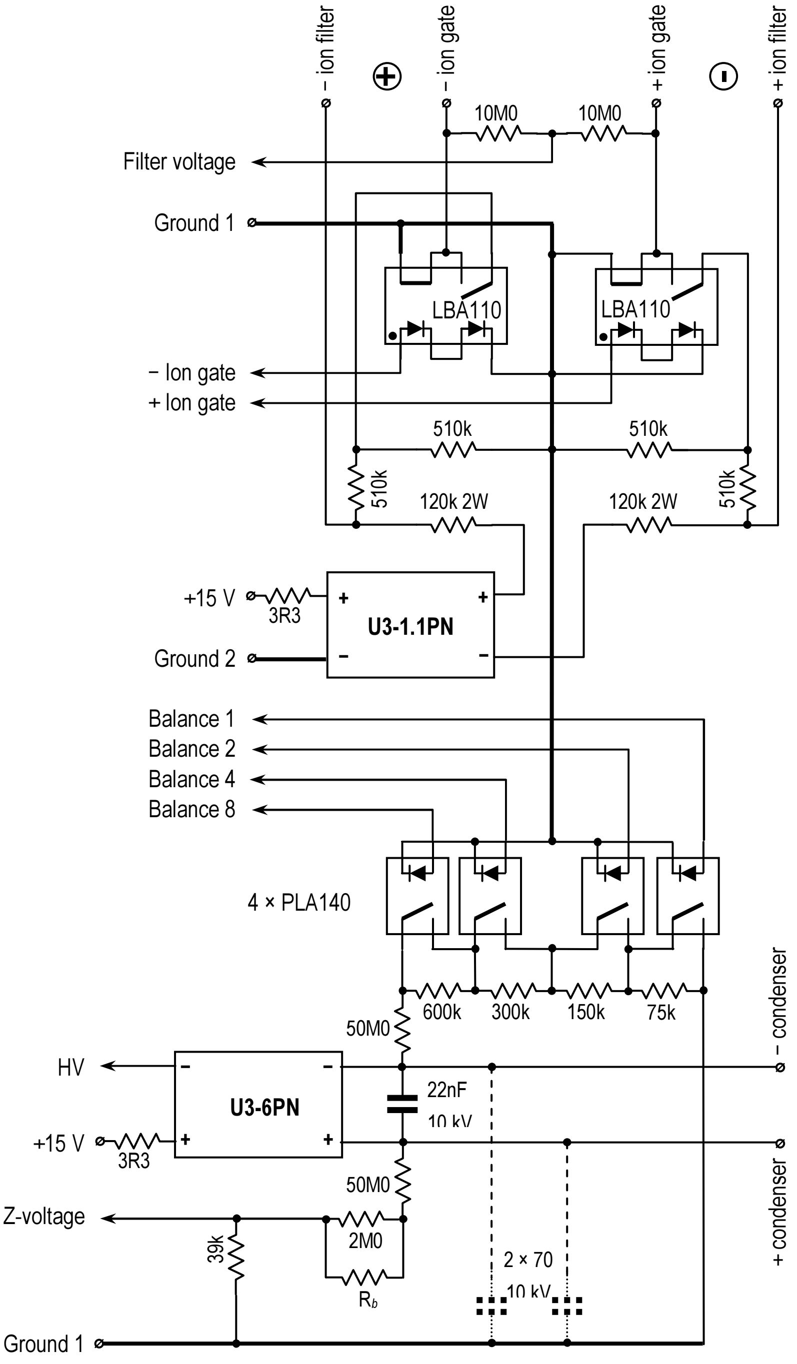
The outline diagram of BSMA3.

Two aspiration condensers are made as mirror images of each other. The electric bridge is shaped by two equal resistors R1 & R2 and two equal capacitors C1 & C2, which are formed by the repelling electrodes and collector electrodes of the aspiration condensers. The bridge is powered from a well-insulated source of high voltage that can be switched on and off under the control of a computer. The balance is adjusted so that R1×C1 ≈ R2×C2. The repelling electrode of the left condenser is negative and the repelling electrode of right condenser is positive, but the absolute values of the voltages are equal. The electric currents induced on the collector electrodes are of opposite polarity and compensate each other. Thus the electrometer is not sensitive to changes in the separating voltage as long as the balance of the bridge is exact. The capacitors C3 and C4 about 70 pF are formed by the connection cables and the parasitic capacitances of the construction. They play a minor role in the relaxation process but have a small positive effect suppressing the signal noise.

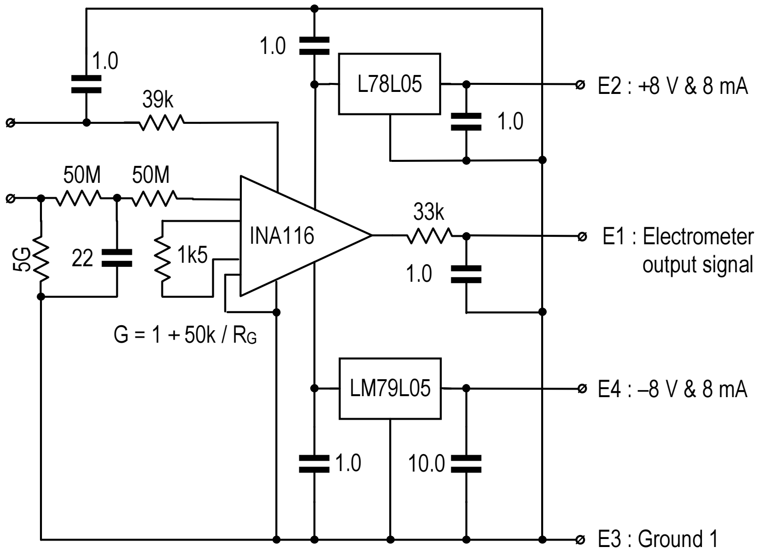
Electric diagram of the control circuit: left part



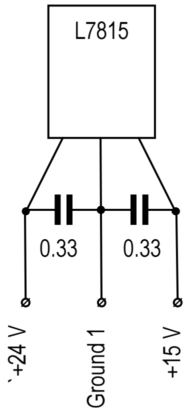
Electric diagram of the control circuit: right part

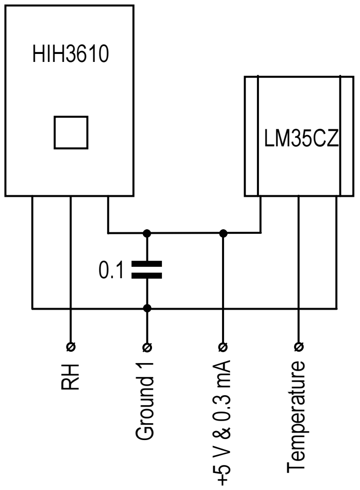


Electric diagram of the electrometric amplifier



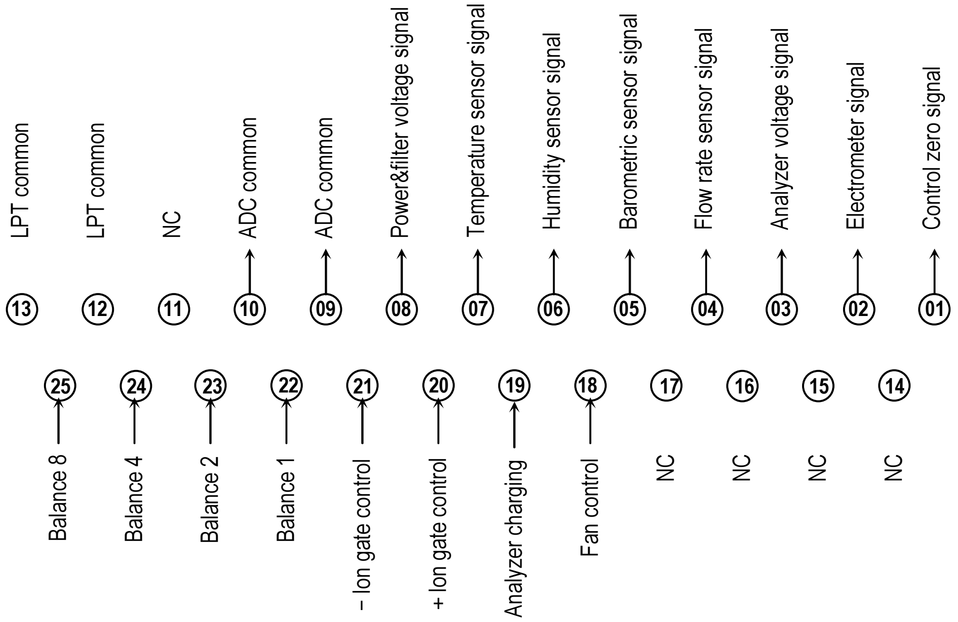
Electric diagrams of the 15 V stabilizer and meteosensors





Two 300 Ω resistors MP930 used for heating of insulators can be connected to 15 V or 24 V sockets.

BSMA3 connector:



Cables from the junction box to BSMA: long, computer LPT: medium, ADC: short.

Cable junction box:

BSMA01 black	ADC01 brown
BSMA02 brown	ADC02 red
BSMA03 red	ADC03 orange
BSMA04 orange	ADC04 yellow
BSMA05 yellow	ADC05 green
BSMA06 green	ADC06 blue
BSMA07 blue	ADC07 violet
BSMA08 violet	ADC08 gray
BSMA09 gray	ADC23 pink+black
BSMA10 white	ADC25 green+black
BSMA11 pink	NC
BSMA12 light green	LPT25 green+white
BSMA13 black+white	LPT23 green+white
BSMA14 brown+white	NC
BSMA15 red+white	NC
BSMA16 orange+white	NC
BSMA17 green+white	NC
BSMA18 blue+white	LPT02 red
BSMA19 violet+white	LPT03 orange
BSMA20 red+black	LPT04 yellow
BSMA21 orange+black	LPT05 green
BSMA22 yellow+black	LPT06 blue
BSMA23 green+black	LPT07 violet
BSMA24 gray+black	LPT08 gray
BSMA25 pink+black	LPT09 white

Ground policy: Control common LPT23&25 is not connected to the ground in the BSMA. It can be connected or not connected to the ground in the computer.
ADC common and power minus are connected together and to the BSMA case in the control PCB. There may appear a low potential on the fan zero and on the minus in the power unit due to the drop of voltage on power wires. Three external cable shields are connected with each other and they are connected to the case of the BSMA and case of the computer via connector frames. Thus the cases of BSMA and the control unit (computer) are connected to each other through the cable shields.

Color codes may vary depending on the manufactures of cables.

Appendix 3. Mobility versus size, temperature and pressure

Mobilities of 2 g/cm3 particles at 950 mb

d:nm	t=-20	t=-10	t=0	t=+10	t=+20	t=+30	t=+40
0.398	2.7573	2.8464	2.9357	3.0235	3.1098	3.1946	3.2781
0.501	2.2232	2.2878	2.3511	2.4132	2.4742	2.5342	2.5931
0.631	1.7725	1.8188	1.8643	1.9089	1.9527	1.9957	2.0379
0.794	1.3841	1.4177	1.4506	1.4829	1.5146	1.5457	1.5763
1.000	1.0545	1.0787	1.1025	1.1258	1.1487	1.1711	1.1932
1.259	0.7768	0.7925	0.8076	0.8222	0.8362	0.8497	0.8627
1.585	0.5176	0.5249	0.5320	0.5390	0.5457	0.5524	0.5589
1.995	0.3282	0.3336	0.3389	0.3442	0.3495	0.3547	0.3598
2.512	0.2174	0.2215	0.2256	0.2297	0.2336	0.2376	0.2414
3.162	0.1468	0.1497	0.1526	0.1554	0.1582	0.1609	0.1636
3.981	0.0989	0.1009	0.1028	0.1047	0.1065	0.1084	0.1102
5.012	0.0660	0.0673	0.0686	0.0699	0.0711	0.0723	0.0735
6.310	0.0437	0.0446	0.0454	0.0462	0.0470	0.0478	0.0486
7.943	0.0287	0.0293	0.0298	0.0303	0.0309	0.0314	0.0319
10.000	0.0188	0.0191	0.0195	0.0198	0.0201	0.0205	0.0208

Mobilities of 1 g/cm3 particles at 1000 mb

d:nm	t=-20	t=-10	t=0	t=+10	t=+20	t=+30	t=+40
0.398	3.1232	3.2241	3.3252	3.4246	3.5224	3.6185	3.7130
0.501	2.3779	2.4470	2.5147	2.5811	2.6464	2.7105	2.7735
0.631	1.8096	1.8569	1.9033	1.9488	1.9935	2.0374	2.0805
0.794	1.3692	1.4024	1.4350	1.4669	1.4982	1.5290	1.5593
1.000	1.0237	1.0473	1.0703	1.0929	1.1151	1.1369	1.1583
1.259	0.7464	0.7614	0.7760	0.7900	0.8034	0.8164	0.8289
1.585	0.4946	0.5016	0.5084	0.5151	0.5215	0.5279	0.5341
1.995	0.3128	0.3179	0.3230	0.3281	0.3331	0.3380	0.3429
2.512	0.2069	0.2108	0.2147	0.2186	0.2224	0.2261	0.2298
3.162	0.1396	0.1424	0.1451	0.1478	0.1504	0.1530	0.1556
3.981	0.0940	0.0959	0.0977	0.0995	0.1013	0.1030	0.1048
5.012	0.0628	0.0640	0.0652	0.0664	0.0676	0.0687	0.0699
6.310	0.0416	0.0424	0.0432	0.0439	0.0447	0.0455	0.0462
7.943	0.0273	0.0279	0.0284	0.0289	0.0293	0.0298	0.0303
10.000	0.0179	0.0182	0.0185	0.0188	0.0192	0.0195	0.0198

Mobilities of 2 g/cm3 particles at 1000 mb

d:nm	t=-20	t=-10	t=0	t=+10	t=+20	t=+30	t=+40
0.398	2.6198	2.7044	2.7892	2.8726	2.9546	3.0352	3.1145
0.501	2.1123	2.1737	2.2338	2.2928	2.3508	2.4078	2.4637
0.631	1.6841	1.7282	1.7713	1.8137	1.8553	1.8961	1.9363
0.794	1.3152	1.3470	1.3783	1.4089	1.4391	1.4686	1.4977
1.000	1.0020	1.0250	1.0476	1.0697	1.0914	1.1128	1.1337
1.259	0.7381	0.7530	0.7674	0.7812	0.7945	0.8074	0.8197
1.585	0.4918	0.4988	0.5056	0.5122	0.5186	0.5249	0.5310
1.995	0.3119	0.3170	0.3221	0.3271	0.3321	0.3371	0.3419
2.512	0.2066	0.2105	0.2144	0.2183	0.2220	0.2258	0.2294
3.162	0.1395	0.1423	0.1450	0.1477	0.1503	0.1529	0.1555
3.981	0.0940	0.0959	0.0977	0.0995	0.1013	0.1030	0.1047
5.012	0.0628	0.0640	0.0652	0.0664	0.0676	0.0687	0.0699
6.310	0.0416	0.0424	0.0432	0.0439	0.0447	0.0454	0.0462
7.943	0.0273	0.0278	0.0284	0.0289	0.0293	0.0298	0.0303
10.000	0.0179	0.0182	0.0185	0.0188	0.0192	0.0195	0.0198

Mobilities of 2 g/cm3 particles at 1050 mb

d:nm	t=-20	t=-10	t=0	t=+10	t=+20	t=+30	t=+40
0.398	2.4954	2.5759	2.6567	2.7361	2.8142	2.8910	2.9665
0.501	2.0121	2.0704	2.1277	2.1839	2.2391	2.2934	2.3467
0.631	1.6042	1.6461	1.6872	1.7276	1.7672	1.8061	1.8443
0.794	1.2528	1.2831	1.3129	1.3421	1.3707	1.3989	1.4266
1.000	0.9545	0.9764	0.9979	1.0190	1.0396	1.0599	1.0799
1.259	0.7032	0.7173	0.7310	0.7442	0.7569	0.7691	0.7808
1.585	0.4685	0.4752	0.4816	0.4879	0.4940	0.5000	0.5059
1.995	0.2971	0.3020	0.3069	0.3117	0.3164	0.3211	0.3257
2.512	0.1968	0.2006	0.2043	0.2079	0.2115	0.2151	0.2186
3.162	0.1330	0.1356	0.1382	0.1407	0.1432	0.1457	0.1481
3.981	0.0896	0.0914	0.0931	0.0948	0.0965	0.0981	0.0998
5.012	0.0598	0.0610	0.0622	0.0633	0.0644	0.0655	0.0666
6.310	0.0396	0.0404	0.0411	0.0419	0.0426	0.0433	0.0440
7.943	0.0261	0.0266	0.0270	0.0275	0.0280	0.0284	0.0289
10.000	0.0170	0.0174	0.0177	0.0180	0.0183	0.0186	0.0189