

Balanced Scanning Mobility Analyzer

BSMA

ABBREVIATED MANUAL
PRELIMINARY EDITION

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1. Principle and Structure of the BSMA

1.1. Objectives

The rise of airborne particles or nucleation is a fundamental process in atmosphere. The mechanism of nucleation in natural air is poorly understood. One of the key problems is the role of ion-induced mechanism in the real atmosphere. Simultaneous measurement of concentration of charged and neutral nanoparticles is an accepted method to detect the ion-induced nucleation. Charged nanoparticles are called the intermediate air ions in atmospheric electricity research. Atmospheric air consists typically of several hundreds of charged clusters or small air ions of both polarities in one cm^3 . The maximum diameter of a stable cluster is about 1.6 nm and corresponding electric mobility about $0.5 \text{ cm}^2 \text{V}^{-1} \text{s}^{-1}$. Concentration of charged particles in the size range of 1.6–6 nm is usually very low and does not exceed few tens of particles per cm^3 . The concentration of a size fraction of charged nanoparticles is typically below of 10 cm^{-3} . Charged nanoparticles can be reliably measured collecting the electric current carried by particles. Thus the measurement of these particles is difficult due to the very low signal in the instrument. If a size fraction contains of 10 particles per ccm and the air flow rate is 1 liter per minute then the electric current of the fraction is $27 \times 10^{-18} \text{ A}$. This is essentially less than the noise level of the best instruments (about $1 \times 10^{-16} \text{ A}$) when applied in atmospheric conditions.

The objective of the development of BSMA was to get a reliable and simple instrument to measure the fraction concentrations of charged nanoparticles down to 10 cm^{-3} in atmospheric air with time resolution that enables to detect the development nucleation bursts in atmosphere.

1.2. Known methods and problems

Two alternative methods of mobility analysis are drift tube or time of flight method and the aspiration method. Drift tubes are popular in laboratory measurement, where high concentrations of charged particles are available and high mobility resolution is required. Disadvantage of drift tubes is low sensitivity and difficulties when the particles are larger than molecular clusters. The aspiration method is commonly preferred in atmospheric measurements. Principles of the aspiration method and classic instruments are described in the book (Tammet, 1970).

The aspiration analyzers are classified according to the way of mobility separation into integral instruments, first order differential instruments and second order differential instruments. Second order differential method offers the best mobility resolution. Its only disadvantage is most complicated design of the instrument that is of secondary importance. We will consider only the second order differential aspiration analyzers below.

Two kinds of aspiration analyzers are known: the analyzers with air carried outlet stream of particles and the analyzers with collecting the particles inside of the aspiration condenser. In aerosol research the first kind of instruments called DMA is popular. The advantage of a classic DMA is high sensitivity offered by numerical particle count when CPC used to detect the particles in the outlet airflow. Thus the air flow rate in a classic DMA is low that is well suited for laboratory applications. The disadvantage is limitation in nanometer range caused by the size limit of CPC. Very small particles should be collected in a Faraday cage filter and the advantage of CPC sensitivity is lost. If one should detect only the charged particles the CPC is useless even in case of large particles.

Collecting of the particles inside of the aspiration condenser is common in atmospheric electricity research. This is technically much simpler method than using of an external Faraday cage filter. An external filter is especially troublesome in occasion of high flow rates when the aerodynamic power loss in a fibrous filter will be high and the principle of electrostatic filter should be applied. Electrostatic filter should be powered from an

electrometrically insulated power source, preferably from embedded battery and HV converter. However, alternative method of collecting of particles inside the instrument has a serious disadvantage: the separating voltage of the analyzer should be very stable to avoid the errors caused by induced current. In common instruments the extremely stable high voltage sources are used. If the mobility distribution should be measured then two methods are possible. Usually, the high voltage is changed step by step and the input of electrometric amplified is short-circuited during voltage commutation. Another possibility to avoid induced currents is the multichannel method: the voltage is unchanged and the analyzer consists of many collecting electrodes corresponding to different mobilities. Multichannel method developed in Tartu University (Tammet et al., 2002) offers best performance when considering the size and time resolution in occasion of very low concentration of particles. The multichannel method is used for air ion mobility distribution measurement in the Tahkuse station (Tammet et al., 1987).

A specific disadvantage of multichannel method is that the measurement errors are specific for channels and it is not easy to prove that a peculiarity in measured mobility distribution is not caused by technical trouble in individual mobility channels.

A known alternative of the multichannel method is continuous scanning of the mobility distribution in the analyzer where induced current is compensated using a balanced bridge circuit. This principle was probably first used by Erikson (1924). Tartu University has long experience with a bridge circuit instrument designed for laboratory experiments (Tammet et al., 1977).

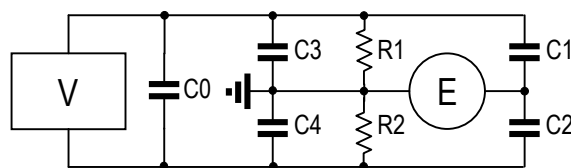


Figure 1. The bridge circuit.

1.3. Principle of BSMA

Oldest prototype of the present instrument is the mobility analyzer by Erikson (1924). BSMA is based on the bridge circuit shown in Figure 1 where electrometric amplifier E is connected in the diagonal of a bridge formed by resistances R1, R2, and capacitances C1, C2. One of the capacitances is filled by air under the study and the current in this capacitor is to be measured. The second capacitor is passive and should not conduct electricity. The bridge is powered from a well-insulated source of high voltage V that can be switched on and off during measurements. The capacitances C3 and C4 are parasitic one and play minor role in the measuring process. The mobility scanning is performed by decay of voltage during discharging of the large capacitance C0 after disconnecting the power from the high voltage source V. The discharging process is nearly exponential with time constant about 4 seconds in the present instrument. Two decades of mobility are scanned during about 19 seconds. An additional second is added to the period of scanning for charging of the capacitance C0.

In the ordinary bridge circuit instruments one capacitance C1 is the capacitance of the collecting electrode and second capacitance C2 is the capacitance of a special compensation condenser. These capacitors are exposed for different air conditions that cause fluctuations in the bridge balance. An innovation proposed by Komarov et al. (1961) is used in BSMA, which consists of two identical aspiration condensers. Both capacitances C1 and C2 are the active capacitances of collecting electrodes of measuring condensers and 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 deionized by means of controlled electrostatic inlet filter.

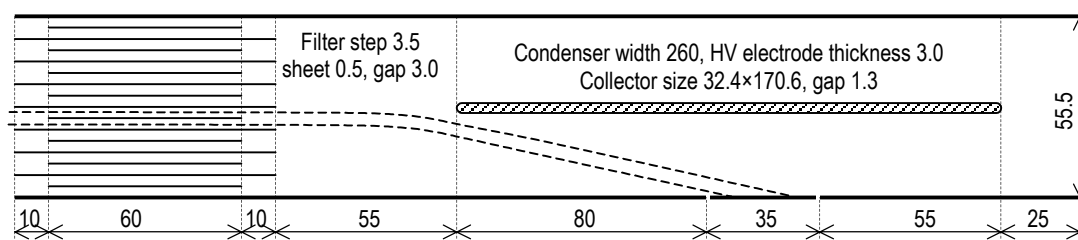


Figure 2. Section of an aspiration condenser in BSMA.

1.4. Structure of BSMA

BSMA is equipped with plain aspiration condensers like the instrument by Erikson (1924). Draft of the section of the condenser is shown in Figure 2. The inlet air is passed through a 80 mm long filter section made of parallel plates. This section suppresses the carried on turbulence that is an essential source of transfer function broadening in occasion of atmospheric measurements (Tammet, 1970). Standard air flow rate in one condenser is 22 l/s and velocity between separating electrodes 1.6 m/s. The Reynolds number of the air flow in filter is about 400 and between the separating electrodes about 3000. It is known that widely spread belief about harmful effect of high Reynolds number is not true in occasion of a short particle separation region (Tammet, 1970). High values of Re may appear even favorable for mobility resolution (Rosell-Llompart et al., 1996). The upper and lower plate of the condenser and all seven long electrodes of the filter are connected to ground. The eight short electrodes may be connected to the permanent voltage of 400 V or to the controlled voltage of 0 or 200 V. In standard regime only the two electrodes of central sections are controlled and three lower sections on Figure 2 are permanently locked for ions by the electric field. Mobility of ions that could pass the locked sections is less than $0.01 \text{ cm}^2 \text{V}^{-1} \text{s}^{-1}$. Such a ions could reach the collecting electrode only when passing through lowest section of the filter. To avoid the effect of these ions the voltage on the filter has opposite polarity when compared with voltage on the central repelling electrode of the analyzer section. As a result the low mobility ions are shifted up in the lowest section of the filter more than they will be shifted down in the analyzer section. There may remain a minor amount of low mobility ions passing the second slit of the filter and reaching collector. Systematic effect of these ions in measurements is fully eliminated by the modulation principle of measurement.

Ion current is collected in a 33 mm long and 170 mm wide collector that is fastened using heated insulators made of ULTEM (polyether imide). The bridge capacitances C_1 and C_2 are made of the capacitances between the central repelling electrodes and the collectors of two aspiration condensers. The collectors of both condensers are connected with each other and with the input of the electrometer.

The controlled sections (see dotted trajectories of ions in Figure 2) of the filter are used as inlet gates. During measurements the scans of the mobility distribution are performed alternately with closed both inlet gates and one opened inlet gate. The mobility distribution is calculated subtracting the result of closed-gate scan from the result of open-gate scan.

The balance of the bridge is not perfect enough for immediate use of a record of a single scan. However, the balance is stable enough to compare neighbor scans and calculate differences due to the change of inlet regime from scan to scan. Thus the modulation eliminates the effect of bridge disbalance.

In the analyzer section a voltage up to 3 kV is applied to the central repelling electrode. The ions deposited on the narrow collector section (see Figure 2) of the lower plate are counted by the electrometric amplifier. The estimate of the transfer function of the instrument is discussed in article 9 "Calibration of the instrument".

2. Installing of the Instrument

BSMA is packed in a transport box. The box consist of

1. Main unit of BSMA.
2. Controlling computer.
3. PICO ADC-16.
4. Serial cable for ADC-16.
5. 24 V power supply for BSMA.
6. Special cable with three connectors and a connecting box.
7. Screwdrivers and spare screws.

The normal position of the instrument is with horizontal airflow. On this occasion the height of the instrument is 36 cm, the width is 33 cm and the length along the air flow is 48 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 of the measurement and recording the data.

The air is sucked in through two openings of 260 (height) \times 58 (width) mm in the front end of the instrument (see Figure 5). The width of the two inlet openings together with separating part of the front panel is 158 mm. The air flows out from round opening of diameter 220 mm in the rear end. The internal pressure drop generated by fan is about 200 Pa. This is not a high value and the instrument is a little 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 4% error of the internal air flow velocity. It is recommended to install the instrument for stationary measurements so that the air will flow out from the same side of the building as the inlet (see draft in Figure 3). The cross section of the external air channel should be at least 4 dm².

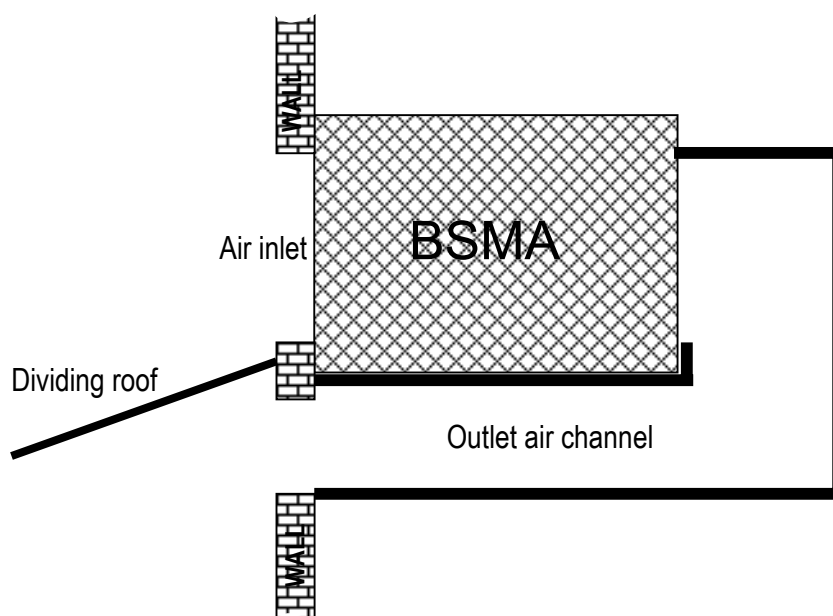


Figure 3. Installation of the BSMA insensitive to wind

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

After the instrument has been placed the electrical connections have to be made. A special triple-connector cable should be connected according to the marks on the connectors with the BSMA, 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 power inlet in a small gray box of the triple-connector cable. This box has two parallel sockets for power, one of them is good for ZVC65SG24 and second for Mascot 2020 power unit. NB: the center electrode of socket must be positive.

Ground could be connected to any cover screw of the BSMA. The ground connection is recommended because electric field around the case of the instrument could disturb admission of ions and charged particles into the inlet of the instrument. BSMA is relatively insensitive to weak external electric fields due to the high ventilation rate of about 45 l/s.

3. Basic Software

The instrument is accompanied with basic software saved in the folder BSMA on the hard disk of included computer and diskettes. The folder includes 5 files BSMA01.EXE, BSMA.INI, BSMA_S01.EXE, BSMA_T01.EXE, DELAY.EXE and subfolders PAS and DATA. The subfolder PAS contains Turbo Pascal source codes BSMA01.PAS, BSMA_S01.PAS, BSMA_T01.PAS, and DELAY.PAS. The subfolder DATA is initially empty, the results of measurements will be saved there.

The program BSMA01 and the calibration file BSMA.INI are sufficient to test and control the instrument, and carry out standard measurements. The program DELAY is required only when changing the computer, it allows to measure the computer-generated delay correction factor. The programs BSMA_S01 and BSMA_T01 work independent of the instrument. They could be used in another computer to perform basic transformations of the initial data recorded on the measurement control computer using BSMA01.

When launched the program BSMA01 displays an initial menu:

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 permanently closed inlet gates),
 X - eXit the program.**

Please press a selective key and ENTER for confirmation!

Operation "C" is recommended before the measurements. Operations "T" and "N" are described in article 8 "Testing of the instrument" and operation "M" in article 4 "Normal operation". BSMA01 uses a calibration file BSMA.INI described in article 9 "Calibration of the instrument".

4. Normal Operation

When starting the measurements the computer should be booted under DOS or DOS-based operation system such as Windows 95 or Windows 98. The included computer is prepared to boot under DOS and launch Norton Commander from autoexec.bat. Running in a normal window of MS Windows is not allowed because the regular background operations carried out by Windows perturb the operation of the instrument. If Windows is the basic operation system of the computer then are three alternatives:

- press F8 during booting and choose DOS command prompt regime,
- restart the computer in DOS mode from the shut down menu,
- boot the computer from a floppy disk.

The program BSMA01 can be launched from the Norton Commander, immediately from the command line BSMA01.EXE or from TURBO PASCAL using BSMA01.PAS. Warning: BSMA01.EXE should not be included into AUTOEXEC.BAT. The active folder should contain a calibration file BSMA.INI and a subfolder DATA. The power of the BSMA could be switched on when BSMA01.EXE is running and the computer has displayed the introductory menu. For a normal operation the regime "M" should be chosen.

If the selective key "M" and "ENTER" are pressed the computer performs some initialization operations and displays a measurement screen with a blinking heading "stopped, press a control key!". Control keys are explained on the screen. Next, the default polarity regime can be modified. There are three variants of the polarity regime: only positive particles, only negative particles or alternately negative and positive particles. The polarity alteration period is one measuring cycle of about 3 minutes. It should be considered that alternating regime results in a loss in the time resolution because the composite cycle will last about 6 minutes. When the polarity regime has been chosen the measurement can be started pressing Ctrl+R. When the program is running, the control keys remain active, but have an effect only after the current 3-minute cycle has been completed.

During measurements the computer screen is as shown in Figure 4. The Figure has been created using the measurement simulator and does not correspond to real measurements.

BSMA01.EXE version HT20030311								scanning mobility distribution	
Parameter	Values of parameters ...							Regime & Ctrl	
Time HHMM	21:06	21:08	20:59	21:01	21:02	21:04	21:05	+ particles = P	
T : C	20.6	20.6	20.6	20.6	20.6	20.6	20.6	- particles = N	
RH : %	52.0	52.0	52.0	52.0	52.0	52.0	52.0	Alternately = A	
p : mb	1025.1	1025.1	1025.1	1025.1	1025.1	1025.1	1025.1	Stop = S	
+noise+	-A-	+	+A+	-A-	+8+	-A-	+9+	Exit = X	
Mobility↓	Fraction concentrations cm-3 ...							1 open	closed
0.03-0.06	22		31	-4	-29	12	1	-16	-11
0.06-0.10	-20		10	40	-14	11	-4	18	3
0.10-0.18	-0		5	2	22	-20	40	-10	4
0.18-0.32	30		46	19	42	2	26	38	-21
0.32-0.56	40		93	50	101	66	86	116	5
0.56-1.00	103		142	75	135	72	88	129	46
1.00-1.78	152		137	115	129	94	131		0
1.78-3.16	115		101	102	103	150	107		-28
Sum	444		566	400	490	388	474		
Use Control+key to change the regime. Controls act when the program is stopped or at the end of a 9-scan cycle. Data are saved every sharp hour and when the program is terminated.								Balance	41 %
								Fan	23.3 V
								EM bias	0.4 mV

Figure 4. Computer screen during measurement (a simulated instance).

Measurement results are printed in columns on the screen. The empty column corresponds to the running cycle. Time is indicated for the beginning of a cycle. During a cycle the computer measures the air parameters and fan voltage, and carries out the calibration of the discharge process of the high voltage capacitor C0 feeding the bridge. When calibration is completed then nine 20-second scans are performed according to the scheme 101010101, where 1 marks a scan with an open inlet gate and 0 marks a scan with closed inlet gates. The number of scans required for completing the running cycle is displayed ahead of the word "open". An 16-component vector is an immediate result of a scan. The scan results are displayed in the right side window under the headings "open" and "closed" that show the status of the inlet gate. There is not enough space for 16 components on the screen. Thus the averages of the neighboring fraction pairs are displayed, and the mobility intervals shown on the left are of double width when compared with the measured and saved fractions. The zero scan is compared with the former zero measurements and if the average drift is less than 2 ADC steps, the zero is adjusted by averaging the new and old values of the zero vector. When the drift exceeds 2 ADC steps, then an asterisk is displayed between the words "open" and "closed". The result of a cycle is calculated as a difference between an extreme-eliminated average of five open inlet scan vectors and the zero vector. The extreme-eliminated average of n values is defined as an average of n-2 values, where the minimum and maximum values of a full sample are not included.

As an extra result the estimate of the measurement noise is calculated comparing four zero scans performed during a cycle. The noise index is displayed in the upper part of the cycle column between the polarity signs. Noise index displayed by a number certifies high quality

of the measurements. If the noise index exceeds 9, it is saved as a number but replaced by a letter on display. “A” corresponds to the values of 10...19, “B” to the values of 20...29 etc. “A” is a normal value and “B” is bad. Numerical value of the noise index is interpreted as an estimate of the noise of one fraction in measured mobility distribution.

Electrometer bias voltage and bridge balance are checked at the launch of the program and later once per hour. The values in the lower right-hand corner are used for the technical diagnostics of the instrument. Normal values of these parameters are:

- bridge balance 5...95 %
- fan voltage 22...24 V
- electrometer bias -3...+3 mV

If the bridge balance is after few working hours still out of the range, the service operation of manual balancing is recommended (see article 8 “testing of the instrument”). The measurements remain valid until the message “Electrometer overload” will systematically appear in the first line of the screen. If the fan voltage is out of the range, the power unit should be replaced. ZVC65SG24 and Mascot 2020 both are proper power units for BSMA. The manufacturer certifies the bias of the electrometric amplifier at -5...+5 mV. However, the bias more than 3 mV is not recommended because a high bias is often accompanied with an enhanced noise level. The best amplifiers have the bias less than 1 mV.

5. Data Files

The instrument control and measuring program BSMA01 saves mobility distribution files. File names are automatically compiled. Two output files are saved simultaneously: a diurnal file BSyymmdd.txt or BSyymmdd.xl and a monthly file BSyymm00.txt or BSyymm00.xl (the extension is selected in BSMA.INI). The prefix BS is reserved for immediate measurement files. yy, mm and dd are the numbers that mark the year, month and day when the file is created. Data are saved every sharp hour and at the exit from the program. The program looks for existing output files in the subfolder DATA of the active folder. If the file is found then it is appended, if not, a new file will be created. The content of a diurnal and monthly file is identical; the only difference is that a new diurnal file will be generated every day. The diurnal files are good for operative data inspection and monthly files are good for data archives.

The first line of a file is a header that helps to identify the columns when inspecting the data using MS EXCEL or a text editor. The header is a line of 26 tab-separated words corresponding to 26 columns of the data table. Following lines consist each of 26 tab-separated numerical values. Columns of the data file are explained in Table 1. Time is specified for the beginning of the cycle. The measuring period is shown as rounded to sharp minutes. The value of the period is always saved as 3.

Regime codes are:

- 1 = negative charged particles and clusters,
- 0 = noise check regime, both inlets permanently closed,
- 1 = positive charged particles and clusters,

The mobility fractions are defined with fixed mobility limits and their size limits can vary dependent on the air temperature and pressure. Mobility limits are expressed in $\text{cm}^2\text{V}^{-1}\text{s}^{-1}$. The mobility of $0.03 \text{ cm}^2\text{V}^{-1}\text{s}^{-1}$ corresponds to the size of about 7 nm (see Appendix 3). The border between nanoparticles and clusters is about $0.5 \text{ cm}^2\text{V}^{-1}\text{s}^{-1}$ or 1.6 nm.

The data files can be copied for export to removable media e.g. a floppy diskette using the MS DOS copy command line but better is to inspect and copy the files by means of Norton Commander. Norton Commander allows to zip-compress the files pressing Alt+F5.

An example of a data file is presented in Appendix 4.

Table 1

Columns of a file of mobility distribution

No	EXCEL column	Header	Value	Mobility $\text{cm}^2\text{V}^{-1}\text{s}^{-1}$
1	A	YYMMDD	Date YYMMDD	
2	B	HHMM	Time HHMM	
3	C	per	Measuring period, minutes	
4	D	T	Temperature, °C	
5	E	RH	Relative humidity, %	
6	F	p	Air pressure, mb	
7	G	reg	Regime code	
8	H	.03-.04	Fraction concentration, cm^{-3}	0.032–0.042
9	I	.04-.06	Fraction concentration, cm^{-3}	0.042–0.056
10	J	.06-.08	Fraction concentration, cm^{-3}	0.056–0.075
11	K	.08-.10	Fraction concentration, cm^{-3}	0.075–0.100
12	L	.10-.13	Fraction concentration, cm^{-3}	0.100–0.133
13	M	.13-.18	Fraction concentration, cm^{-3}	0.133–0.178
14	N	.18-.24	Fraction concentration, cm^{-3}	0.178–0.237
15	O	.24-.32	Fraction concentration, cm^{-3}	0.237–0.316
16	P	.32-.42	Fraction concentration, cm^{-3}	0.316–0.422
17	Q	.42-.56	Fraction concentration, cm^{-3}	0.422–0.562
18	R	.56-.75	Fraction concentration, cm^{-3}	0.562–0.750
19	S	.75-1.0	Fraction concentration, cm^{-3}	0.750–1.00
20	T	1.0-1.3	Fraction concentration, cm^{-3}	1.00–1.33
21	U	1.3-1.8	Fraction concentration, cm^{-3}	1.33–1.78
22	V	1.8-2.4	Fraction concentration, cm^{-3}	1.78–2.37
23	W	2.4-3.2	Fraction concentration, cm^{-3}	2.37–3.16
24	X	fan	Fan voltage, V	
25	Y	balance	Balance percent	
26	Z	noise	Noise index, cm^{-3}	

6. Simple Data Transformations

The programs BSMA_T01 and BSMA_S01 perform simple transformations of data. These programs could be used on an independent computer that is not busy with measurements. The data transformation programs can be used under MS DOS or any version of Windows. They do not require installation when running under Windows.

BSMA_T01 reads the original data file from the active folder and writes two new data files in the same folder, where the data are averaged over 15 minutes and 1 hour. The structure of the new files is exactly the same as of the initial file. The averaging period is shown in the third column of every line. The names of the output files are a subject of free choice. The averaging is made separately for the lines with different regime codes. The lines from the initial file are chosen for an average if they are in a specified time interval limited with sharp quarters of an hour. If the number of lines to be averaged is less than five, the total average is calculated, if more, the extreme-eliminated average is calculated.

BSMA_T01 can be applied for the processing of size distribution files as well.

The size distribution files can be compiled using the program BSMA_S01. The program reads the original or time-averaged mobility distribution file from the active folder and writes a new data file in the same folder, where the particle size distribution is presented. The file structure is similar to the mobility distribution file structure. Content of columns is explained in Table

2. The size fraction borders correspond to the logarithmically uniform distribution where a decade is divided into 10 fractions.

Regime code is -3 or 3 in the size distribution lines that allows identifying the lines when different distributions are merged in the same file. The sign of the regime code shows the polarity of particles. 16 fraction concentration columns in the table represent two separate size distributions with the step factor values of $10^{3/10}$ and $10^{1/10}$. Columns of the rough distribution have physical interpretation:

- 0.4-0.8 nm - single-layer clusters,
- 0.8-1.6 nm - multi-layer clusters,
- 1.6-3.2 nm - fine nanometer particles,
- 3.2-6.3 nm - medium nanometer particles.

In the process of conversion, the data on air temperature and pressure are used and the particle density is expected to be 2 g cm^{-3} . The value of the particle density is essential only in the range of cluster sizes (compare data in Appendix 3 "Mobility versus size, pressure, and temperature").

Table 2

Columns of a file of size distribution

No	EXCEL column	Header	Value in particle regime	Size range, nm
1	A	YYMMDD	Date YYMMDD	
2	B	HHMM	Time HHMM	
3	C	per	Measuring period, minutes	
4	D	T	Temperature, °C	
5	E	RH	Relative humidity, %	
6	F	p	Air pressure, mb	
7	G	reg	Regime code +3 or -3	
8	H	0.4-0.8	Fraction concentration, cm^{-3}	0.40–0.79
9	I	0.8-1.6	Fraction concentration, cm^{-3}	0.79–1.58
10	J	1.6-3.2	Fraction concentration, cm^{-3}	1.58–3.16
11	K	3.2-6.3	Fraction concentration, cm^{-3}	3.16–6.31
12	L	0.4-0.5	Fraction concentration, cm^{-3}	0.40–0.50
13	M	0.5-0.6	Fraction concentration, cm^{-3}	0.50–0.63
14	N	0.6-0.8	Fraction concentration, cm^{-3}	0.63–0.79
15	O	0.8-1.0	Fraction concentration, cm^{-3}	0.79–1.00
16	P	1.0-1.3	Fraction concentration, cm^{-3}	1.00–1.26
17	Q	1.3-1.6	Fraction concentration, cm^{-3}	1.26–1.58
18	R	1.6-2.0	Fraction concentration, cm^{-3}	1.58–2.00
19	S	2.0-2.5	Fraction concentration, cm^{-3}	2.00–2.51
20	T	2.5-3.2	Fraction concentration, cm^{-3}	2.51–3.16
21	U	3.2-4.0	Fraction concentration, cm^{-3}	3.16–3.98
22	V	4.0-5.0	Fraction concentration, cm^{-3}	3.98–5.01
23	W	5.0-6.3	Fraction concentration, cm^{-3}	5.01–6.31
24	X	fan	Fan voltage, V	
25	Y	balance	Balance percent	
26	Z	noise	Noise index, cm^{-3}	

An example of a size distribution file is presented in Appendix 4.

7. Disassembling and Routine Maintenance of the Instrument

Precaution: *All transparent details in the instrument are made of polycarbonate. Polycarbonate is soluble in acetone. Keep acetone and acetone-consisting solvents carefully away of the instrument as the insulators can be damaged when contacted with acetone.*

The inlet grid of the BSMA collects dust and fibers from the air. Thus it needs regular cleaning depending on the level of air pollution. For cleaning the front panel should be detached from the instrument. The grid is made of perforated aluminium and should be manipulated with care to avoid deformation. The grid can be cleaned using a brush and a vacuum cleaner. If a grid is heavily polluted then it could be washed with a detergent (e.g. soap) and water using a brush. Do not use textile because the textile can leave fibers on grid.

The upper and lower panel of an aspiration condenser are made of transparent polycarbonate. When the upper and lower cover panel of the instrument are away the inside of the condensers can be visually inspected. Disassembling of the condensers is troublesome and could be made only in case of critical need.

Procedure of disassembling is following. Take away all five cover panels of the main section of the instrument and leave on only the panels of the fan section. Take away the electrometric amplifier using tweezers for disconnecting of inlet wires. Keep electric contact of one hand with the instrument frame when disconnecting the wires from the electrometer. Turn instrument upside down and switch off all wire connections to the aspiration condensers. Remember well all connections to be able to assemble the instrument again. Turn instrument on the vertical position fan section down, take a 300 mm long Ph1 screwdriver and unscrew eight M4 screws fixing the condensers to the frame of the instrument. The condenser A should be detached first, it should be shifted right to disconnect the connectors from heating resistors between the condensers. Turn the the instrument upside down (handles on the table) and take out the condensers guiding carefully the wires (see Figure 6) through narrow clearance between the frame and a condenser.

For proper cleaning of an aspiration condenser is enough to take away collector panel from the condenser. Screw away 14 M3×8 (do not use longer screws when reassembling!) screws and detach the panel (see Figure 7). The collector is hanging on two yellow cylindrical polyether imide insulators. These insulators can be first cleaned with clean ethyl alcohol and finally with spray of deionized water.

The remaining part of the aspiration condenser should be cleaned without further disassembling. Heavily polluted condenser can be rinsed at first in water with washing powder and then in clean water. Use spray of deionized water for final rinse and dry the condenser properly before assembling of the instrument.

Notice the marks in parts when assembling the instrument. The B condenser should be installed first and fixed with screws when the instrument is in vertical position (Figure 8).

The connectors of heating resistors and the leads from collectors to electrometer should be put in the place before the condenser A is fixed.

When connecting the wires to the filter connect all wires from long electrodes to ground, two wires from short central electrodes to connectors in narrow tube insulators and wires from other short electrodes to connectors in thick tube insulators. Properly connected wiring is shown in Figure 9.

Electrometer unit should be fixed at last. Use tweezers to connect the wires. The connections of the electrometer are shown in Figure 10.

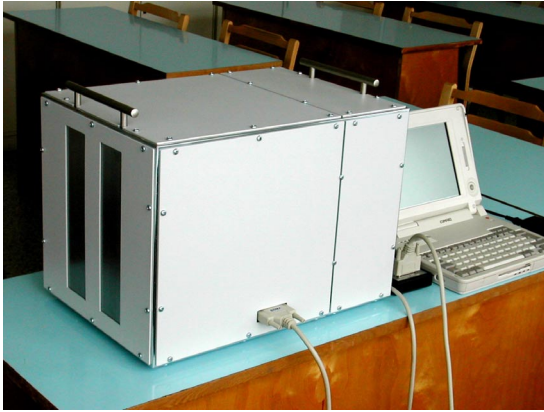


Figure 5. BSMA

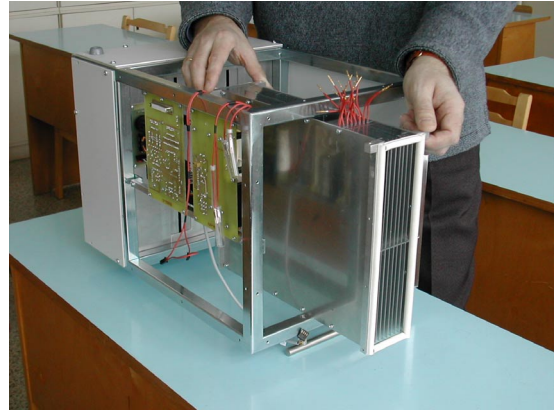


Figure 6. Extracting of an aspiration condenser.

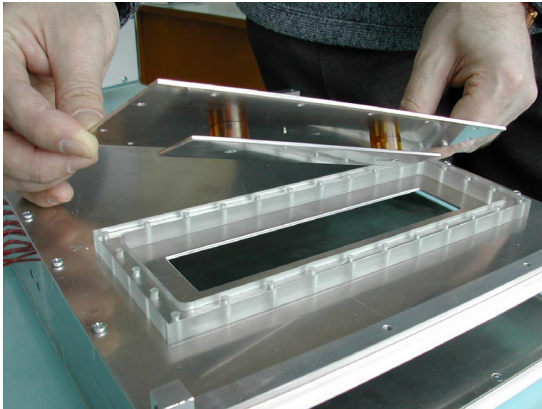


Figure 7. Detaching of a collector panel.



Figure 8. BSMA in vertical position during reassembling.

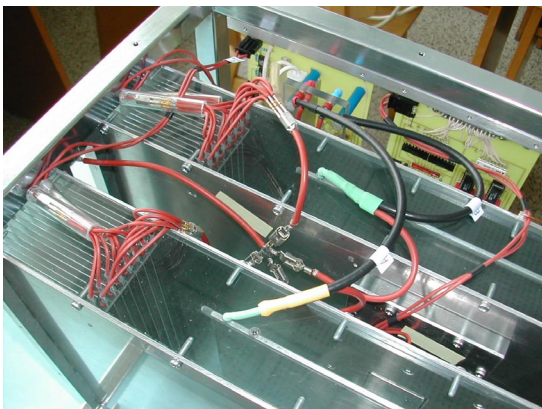


Figure 9. Wiring of aspiration capacitors.

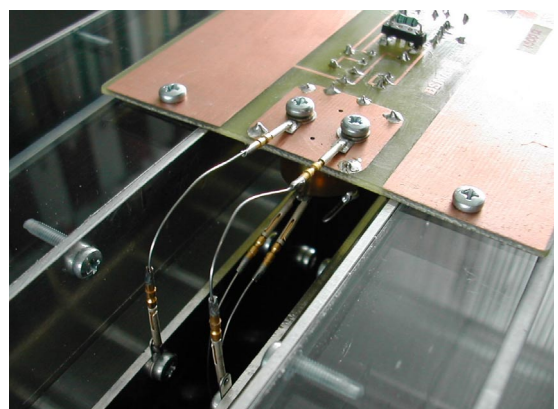


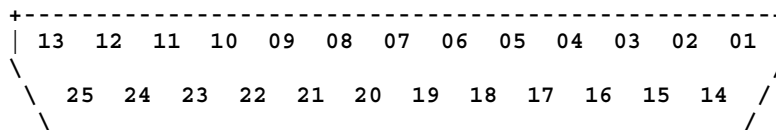
Figure 10. Input connections of the electrometer.

8. Testing of the Instrument

On the occasion of technical problems the test regime of the program BSMA01 can be selected from the initial menu. The computer displays the test menu:

BSMA 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:



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 (# marks the number in the command line):

```

2... 9 : set LPT pin # high and display LPT settings,
-2...-9 : set LPT pin # low and display LPT settings,
space bar: display centiseconds and readings of all 8 ADC channels,
U1...U9 : slide bridge potentiometer wiper # steps up,
D1...D9 : slide bridge potentiometer wiper # steps down,
W       : store wiper position,
S       : show sensor signals,
T1      : test scan (results in ADC counts)
T2      : test scan and saving of the record
T3      : test scan relative to saved record
B       : bridge balance test (do not during the first hour),
Q       : display again the instruction above,
X       : exit the test.

```

Please enter commands:

Numerical commands and space bar could be used to test the computer and ADC when the triple-connector cable is removed and BSMA is not connected to computer. When BSMA is connected the same commands allow control the BSMA controls and measure rough signals explained in Appendix 2. Commands U, D, and W are used to check the automatic balance potentiometer and command B for adjusting of manual balance potentiometer. For adjusting of this potentiometer the left cover panel of the instrument should be off. The multiturn potentiometer is located on the left PCB and it can be adjusted using fine screwdriver. If adjusting is recommended then turn potentiometer at first 360 degrees in recommended direction and later according the displayed results. After balancing the command W (store wiper position) is recommended because the wiper of automatic potentiometer is centered during balancing operation.

In the scan test the immediate counts of ADC are displayed. The correctness of ADC readings is assured in range -8191...+8191 that corresponds to -2.5...2.5 V but the technical range of ADC is twice higher. The electrometer readings are technically limited with value about 12000 by means of zener diodes in the electrical circuit.

It is recommended to have a stable test source of cluster ions that could be placed immediately in the inlet air channel. A radioactive preparation removed from a standard smoke detector is a simple solution. The test source is useful for testing the instrument after partial disassembling and assembling.

The noise of the instrument readings can be tested when the regime "N" is selected from the main menu of BSMA01. The records of N-regime consist of only noise signal that can be analyzed as immediately as after transformations by BSMA_S01 and BSMA_T01 using MS EXCEL or othet programs of data analysis.

9. Calibration of the instrument

9.1. Values of ADC counts

PICO ADC-16 is a factory calibrated instrument. The voltages are measured with the resolution of 13 bit (+ sign) and the value of one count is $2.5 \text{ V} / 8191$. The grid is connected to ADC via a voltage divider $5010000 \text{ k}\Omega$ to $38.9 \text{ k}\Omega$. Thus

the value of one ADC count is **0.393 V**.

and the maximum voltage that could be correctly displayed is **3220 V**.

The electrometer signal is measured with a gain that is determined by replaceable resistor R_g . Value of this resistor must be shown in the file BSMA.INI.

$$\text{Gain} = 1 + 50 \text{ k}\Omega / R_g.$$

Standard resistor is **1500 Ω** and the corresponding gain is **34.3**. Thus the value of one ADC count is **8.89 μV** . The ion current is measured according to the voltage drop on a **5 G Ω** resistor and the value of one ADC count is **1.78 fA** or **11100 e/s**.

9.2. Time constants and regime

The time constant of the scanning voltage is about 4.2 s. The discharging process is not correctly exponential. Thus the calibration of mobility fraction borders is made without assumption of exponential process. All single measurements of ADC are performed by a subroutine that ensures duration exactly 0.1 s. The voltage borders of mobility fractions are known. Every hour the voltage calibration scan is performed and the numbers of measurements corresponding to mobility fractions are counted. During the next hour the electrometer signal is measured just so many times for every fraction as determined by the voltage scanning. These numbers vary from 9 for low mobility fractions until 13 for high mobility fractions.

The electrometer signal is delayed from the voltage regime due three factors: time of passage of ions, time constant of electrometer inlet and time delay in the electrometer outlet filter. Average passage time delay is estimated about 50 ms and electrometer time delay is measured 146 ms. At the ion signal scanning the electrometer readings are recorded just 200 ms later than the voltage reaches the corresponding to the mobility value.

9.3. Mobility calibration

The ideal transfer function of the instrument is triangular with the lower characteristic mobility of 75% of the central characteristic mobility and upper characteristic mobility of 133% of the central characteristic mobility. The characteristic mobilities are calculated as ratio of air flow rate to the flux of electric field. The flux of electric field is calculated solving the Laplace equation on the grid with the step of 0.1 mm. The attempts to measure the air flow rate with different instruments including TSI Air Velocity Transducer resulted in large variation of results. Thus the calibration was performed using freshly generated negative ions in the laboratory air that consists of an admixture of iodine. Ions were generated using a ^{90}Sr beta-source in a specially attached large air flow channel that provides a stable ion concentration of about 30000 cm^{-3} . Iodine forms monomobile ions of mobility 1.75-1.80 $\text{cm}^2\text{V}^{-1}\text{s}^{-1}$ when reduced to standard conditions according to Langevin (see Tammet, 1975). About half of the ions are based on iodine and the iodine line can easily be identified on the background of the spectrum of the ions of different origin. The result was flow rate for one aspiration condenser of 22 liters per second. Another method of calibration according to comparison of ion concentrations measured with BSMA and calibrated integral air ion counter yield the same result.

9.4. Correction of particle adsorption

On the way to the collector the particles pass the inlet grid and parallel-plate filter. Adsorption is estimated theoretically according to Tammet (1970). It follows from calculations that adsorption on the inlet grid is about $0.044 Z^{2/3}$ and adsorption on inlet filter is $0.094 Z^{2/3}$, where Z is expressed in $\text{cm}^2\text{V}^{-1}\text{s}^{-1}$. Relative loss is pretty low for nanometer particles and considerable for cluster ions. The correction is to be made by multiplying the measured values to the correction factor:

$$\text{adsorptioncorrection} := \frac{1}{(1 - 0.044Z^{2/3})(1 - 0.094Z^{2/3})}$$

where Z is central mobility of the fraction.

9.5. Sensor calibration

The signals of temperature, humidity and pressure sensors depend on the values of the measured quantities approximately according to the linear law and the inverse transformation is linear as well:

$$\text{quantity} = a \times \text{signal} + b.$$

Calibration means the evaluation of constants a and b for each sensor. This was done by comparing the signals with the values measured using an aspiration psychrometer and mercury barometer.

Sensors of air pressure and humidity are not precise. Thus the small deviations of BSMA indications from exact values are not sufficient reason to correct the calibration. Calibration file BSMA.INI could be modified when the error exceeds 10 mb for pressure and 10% for humidity.

9.6. Calibration file

All six sensor calibration constants, as well the mobility and concentration calculation constants *voltagefactor* and *concentrationfactor* are saved in the calibration file BSMA.INI. When the calibration will be adjusted in the future, the adjusted values of constants should be written into BSMA.INI that can be edited using any plain text editor. The initial content of BSMA.INI should remain stored in the end of BSMA01.PAS and you could inspect it in Appendix 5 "Program listings".

10. Noise and Time Resolution

The main physical factor of the noise in BSMA is the sedimentation of radon daughters on the electrodes and the following alpha-particle generated ionization inside of the instrument (an alpha-particle can generate up to 200000 ion pairs). The physical limit of time resolution is determined by the time of one scan that is 20 seconds. This limit could be reached when the signal to noise ratio is very high. This could happen only in special laboratory measurements. The charged nanometer particle concentration in natural air is low and averaging of the results of many scans is required to suppress the noise. Nine scans are chosen as minimum in the program BSMA01. When using this program the best time resolution is 3 minutes. Usually the measurement should be averaged over a longer time, depending on the allowed error of fraction concentrations and the actual level of noise.

Another method to suppress the noise is averaging over the mobility scale or the merging of fractions. Thus the sensitivity, mobility resolution and size resolution depend on each other and on the level of measurement noise.

The measurement noise can be estimated when performing measurements in a regime, where the inlet gate is permanently closed. A 320-cycle noise study experiment was made when the instrument was working overnight in unpolluted laboratory air. The noise level appeared practically independent of the fraction that is an indication that the alpha-particle generated

noise is main component of BSMA noise. Exceptions are the two-three largest fractions where the noise level can be 10–20% higher due to the bridge balance noise.

The standard deviation of a fraction concentration can be estimated according to the formula:

$$\sigma = c \sqrt{\frac{\text{number of values per hour}}{\text{number of fractions}}} \text{ cm}^{-3},$$

where the noise constant c depends on the level of airborne of radon daughters that will deposit on the electrodes and generate noise. The value of c in air of a laboratory was according to 10 hours of test measurement $c = 11$.

The statistical distribution of the noise-generated results of the fraction concentration measurement is shown in Figure 11. Statistical distribution is a little similar to Gauss distribution but has some asymmetry and enhanced excess.

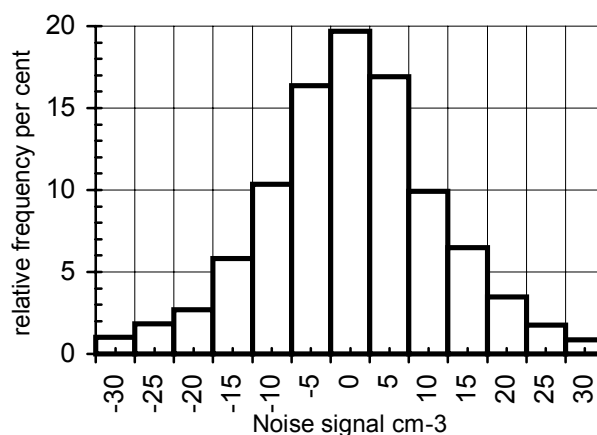


Figure 11. The histogram of fraction concentration noise in 3-minute measurements.

11. Specifications

Size: length cm, width 31 cm, height 32 cm.

Mass: 17.5 kg.

Power: DC 22–24 V, 60 W or
AC 47–63 Hz, 90–260 V, 70 W.

Air flow rate: 0.044 m³ s⁻¹.

Mobility range: 0.032–3.2 cm² V⁻¹ s⁻¹.

Fraction concentration range: 0–40000 cm⁻³.

Mobility resolution: 16 mobility fractions.

Standard deviation of a fraction concentration in conditions of moderate radon concentration

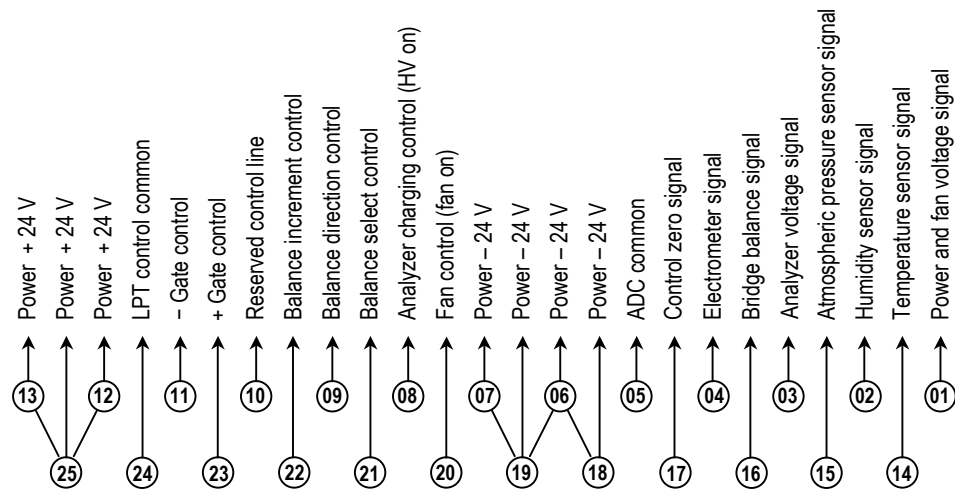
$$\sigma = 10 \sqrt{\frac{\text{number of values per hour}}{\text{number of fractions}}} \text{ cm}^{-3}.$$

12. References

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BSMA connector, controls and signals

Connector



Controls

LPT pin	BSMA pin	Port value	Bit	Function
2	20	1	1	Fan: 0 = off, 1 = on
3	08	2	2	6 kV: 0 = off (scan), 1 = on (charging)
4	23	4	3	- Gate: 0 = open, 1 = closed
5	11	8	4	+ Gate: 0 = closed, 1 = open
6	21	16	5	Balance: 0 = select, 1 = if bit7 = 1 then store (20 ms)
7	09	32	6	Balance: 0 = direction down, 1 = direction up
8	22	64	7	Balance: 0=>1=>0 step up or down (4 μ s)
9	10	128	8	Reserved

Signals

ADC channel	BSMA pin	Function	Approximate transfer coefficients
1	17	Control zero	1 : 1
2	04	Electrometer	1 pA => gain \times 33 mV
3	03	Analyzer voltage	1 : 1280, 3 kV => 2.35 V
4	16	Bridge balance	1 : 2
5	15	Pressure	1000 mb => 2 V
6	02	Humidity	0% => 0.4 V, 100% => 2V
7	14	Temperature	100 C => 1 V
8	01	Fan voltage	1 : 11, 24 V => 2.18 V

Mobility versus size, pressure and temperature

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

Appendix 3

Measurement example

Measurement was carried out in laboratory air. Few minutes after beginning the measurement, the current was switched on in a electrolysis cell filled with solution of natrium tiosulfate, and the same time a small mercury lamp was turned on. As a result a weak nucleation event was generated.

Data table saved by BSMA01

YYMMDD	HHMM	per	T	RH	p	reg	.03-.04	.04-.06	.06-.08	.08-.10	.10-.13	.13-.18	.18-.24	.24-.32	.32-.42	.42-.56	.56-.75	.75-1.0	1.0-1.3	1.3-1.8	1.8-2.4	2.4-3.2	fan	balance	noise
30314	1042	3	20.1	29.2	1037.2	1	15	14	2	3	5	-3	-17	4	-19	-7	13	76	109	77	17	14	23.3	43	10
30314	1045	3	20.1	29.2	1037.2	1	23	-14	-20	0	-8	-20	13	2	0	-5	5	55	107	83	6	12	23.2	43	11
30314	1048	3	20.1	29.1	1037.2	1	35	12	14	29	4	3	6	-18	3	6	6	34	97	86	8	0	23.3	43	14
30314	1051	3	20.1	29	1037	1	58	79	83	85	82	56	25	7	24	4	15	43	79	38	15	-10	23.2	43	12
30314	1054	3	20.3	28.7	1037	1	103	98	116	83	55	41	38	49	10	10	-3	45	88	76	11	9	23.2	43	14
30314	1057	3	20.4	28.5	1037.2	1	92	113	82	78	70	33	31	9	39	4	-4	50	90	60	17	17	23.2	43	13
30314	1101	3	20.4	28.5	1036.9	1	143	132	96	43	24	29	47	22	18	20	21	45	98	42	14	16	23.2	43	9
30314	1104	3	20.4	28.4	1037	1	75	85	49	49	31	36	75	37	25	11	30	40	90	61	46	15	23.2	43	11
30314	1106	3	20.6	28.4	1037.3	1	73	62	42	50	23	37	8	41	17	27	36	81	122	54	20	18	23.2	43	12
30314	1109	3	20.6	28.4	1037	1	40	78	54	36	47	37	52	36	36	1	31	59	137	66	27	14	23.2	43	12

Data table converted from the table above using BSMA_S01

YYMMDD	HHMM	per	T	RH	p	reg	0.4-0.8	0.8-1.6	1.6-3.2	3.2-6.3	0.4-0.5	0.5-0.6	0.6-0.8	0.8-1.0	1.0-1.3	1.3-1.6	1.6-2.0	2.0-2.5	2.5-3.2	3.2-4.0	4.0-5.0	5.0-6.3	fan	balance	noise
30314	1042	3	20.1	29.2	1037.2	3	98	197	-35	21	12	27	59	89	82	27	-15	-10	-10	3	5	14	23.3	43	10
30314	1045	3	20.1	29.2	1037.2	3	91	171	-1	-40	9	24	58	86	68	17	-2	6	-5	-13	-12	-14	23.2	43	11
30314	1048	3	20.1	29.1	1037.2	3	84	149	-3	64	3	23	58	79	53	17	2	-9	4	12	27	24	23.3	43	14
30314	1051	3	20.1	29.0	1037.0	3	49	136	102	331	1	13	35	57	54	26	22	24	57	102	117	111	23.2	43	12
30314	1054	3	20.3	28.7	1037.0	3	84	143	133	355	8	24	53	73	54	16	23	53	56	78	128	150	23.2	43	14
30314	1057	3	20.4	28.5	1037.2	3	85	142	107	335	14	24	47	70	57	15	31	31	46	83	112	140	23.2	43	13
30314	1101	3	20.4	28.5	1036.9	3	71	167	119	296	12	18	40	67	63	38	30	41	48	41	88	168	23.2	43	9
30314	1104	3	20.4	28.4	1037.0	3	111	167	169	217	20	36	55	69	59	39	34	65	70	51	67	99	23.2	43	11
30314	1106	3	20.6	28.4	1037.3	3	90	244	108	186	15	24	51	89	94	62	39	37	33	45	61	80	23.2	43	12
30314	1109	3	20.6	28.4	1037.0	3	104	222	153	211	14	29	61	96	86	41	36	57	60	57	64	89	23.2	43	12

The diagrams compiled according to tables above using MS Excel and MS Word:

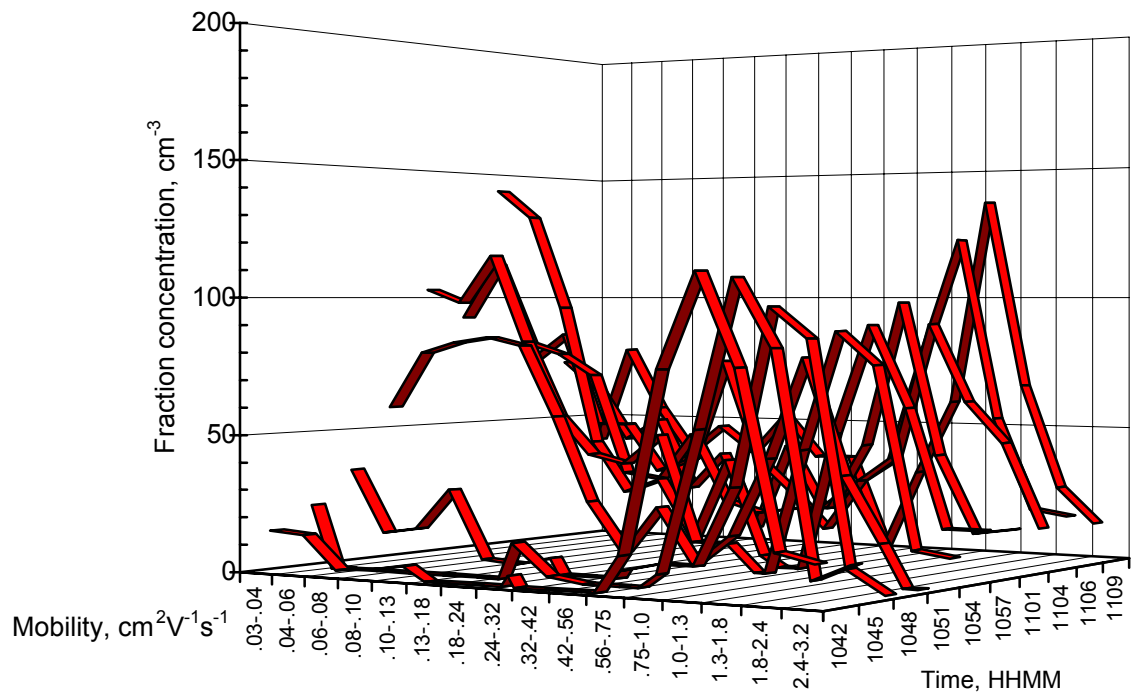


Diagram of mobility distribution.

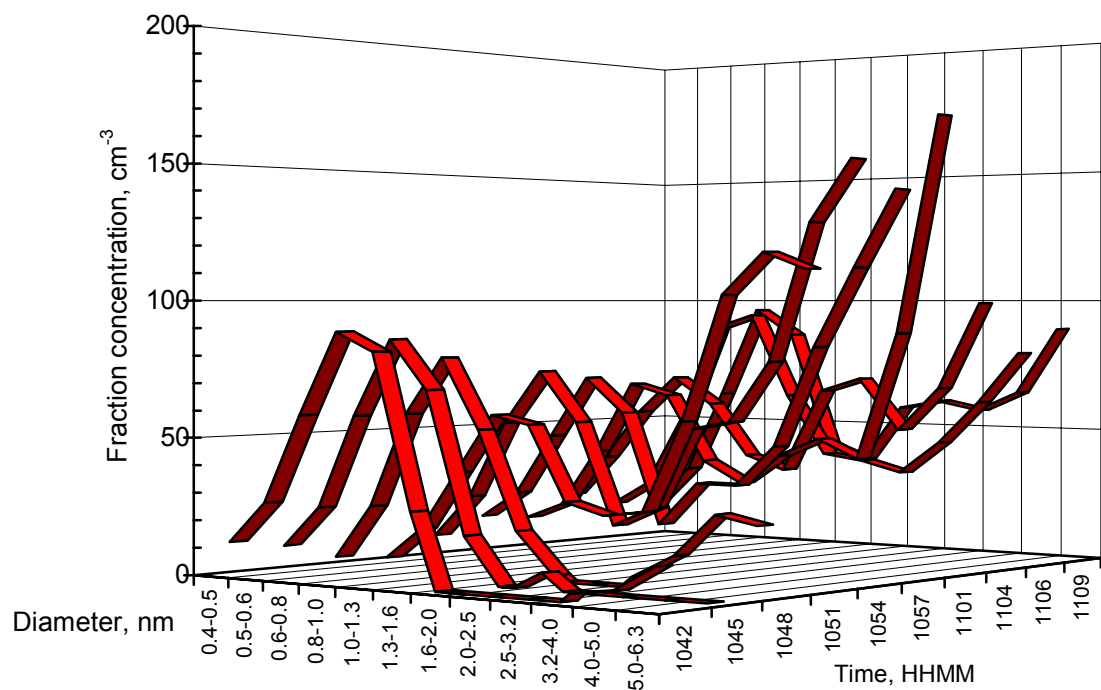


Diagram of size distribution