M. Fierz
ETHZ
Zurich
Switzerland

First experience with the electrical diffusion battery

The Electrical Diffusion Battery

[1]Martin Fierz, [2]Leo Scherrer, [1]Heinz Burtscher
[1] Institut für Sensoren und Signale, Fachhochschule Aargau, 5210 Windisch, Schweiz
[2] Institut für Festkörperphysik, ETH Zürich, 8093 Zürich, Schweiz

1 Today's standard instrument to measure particle size distributions is the SMPS. While it is good at measuring total concentrations and size distributions, it has a poor time resolution, and it is both large and expensive. We have developed an electrical diffusion battery, which can give a rough estimate of the size distribution with a good time resolution. In addition, it is lightweight, portable and potentially cheap.

2 The electrical diffusion battery consists of 5 electrically insulated stages, the first 4 are wire-screen type diffusion stages, and the fifth is a backup filter. Aerosol is deposited on the wire screens by diffusion. The aerosol is charged in a unipolar diffusion charger prior to entering the diffusion battery. We measure the electric current flowing from the 5 stages with sensitive ampèremeters.

3 The diffusion battery can give size information, because particles with a high diffusion coefficient (small particles) are deposited mainly in the first diffusion stage, while larger particles with a small diffusion coefficient get deposited mainly in the last stages. An experiment with monodisperse test aerosols shows an excellent agreement between theory and experiment.

4 Real aerosols are not monodisperse, and we must describe the response of the diffusion battery to real aerosols. For this, we assume an aerosol with a lognormal size distribution which can be characterized by the 3 parameters N, d, and σ. Since we know the deposition fractions of a monodisperse aerosol, we can integrate over the size, and multiply the deposition fractions for each size with the mean charge on the particles, which is a quantity which we can measure. Therefore, we can calculate the five stage currents for any three lognormal parameters.

5 Of course, we really want to solve the inverse problem. We have five measured currents and would like to know the size distribution. Our software can operate in two modes. In the first, it finds the 3 lognormal parameters which describe the 5 measured currents best. In the second mode, it attempts to make a bimodal fit with two lognormal modes. Since this fit is underdetermined (6 parameters for 5 data points), we additionally specify the widths of the lognormal distribution.

6,7 In a couple of experiments, we compared the performance of the diffusion battery with an SMPS and a CPC. The experimental setup consists of two aerosol generators, a salt nebulizer producing an aerosol with a mean diameter of about 100 nm, and a tungsten wire which produces an aerosol of a mean diameter of 10-20 nm. The two sources can be operated individually. The aerosol is neutralized with a radioactive neutralizer and the remaining charged particles are removed in an electrofilter. The neutral aerosol is measured with the diffusion battery, the SMPS and directly with a CPC.

8 The first experiment is done with a single aerosol source. We produced three aerosols of increasing diameter. The results are given in the table. The agreement between the diffusion battery and the SMPS is good, compared for instance with the agreement between CPC and SMPS number concentration. However, the agreement is best in the second case, and a bit worse for the 1st and the 3rd case. There is an explanation for this:

9 In the 1st experiment, the particles have a very small diameter, so that a part of the size distribution is not accessible to the SMPS. This can partly explain the discrepancy in the number concentration between SMPS and diffusion battery.

10 In the 2nd experiment the agreement is truly excellent. The aerosol indeed has a lognormal size distribution, so our assumption for the fit is valid, which leads to a good result.

11 In the 3rd experiment however, the size distribution is not lognormal and this leads our fit algorithm slightly astray.

12 In another type of experiment, we mixed the two aerosols together to produce a bimodal aerosol. This is often seen in engine exhaust, where there is an accumulation mode with a diameter of ~100nm and a nucleation mode with a diameter of about 10nm. First, only the wire generator was turned on, then both generators were turned on, and at last only the salt generator was turned on. The graph on top shows the raw signal of the voltages of the 5 stages of the diffusion battery. Below we have plotted the calculated concentrations of the two modes. The reduction in the small mode after the salt nebulizer is turned on is not an artefact, but can also be seen in the SMPS and is probably due to scavenging by the larger salt particles.

13 This slide shows a comparison of the SMPS data with the diffusion battery result for the bimodal case. While the agreement is of a more qualitative nature, the diffusion battery still gets the two modes approximately right.

14 The last experiment was designed to show the good time resolution of the diffusion battery. The salt nebulizer was turned on the whole time, while the wire generator was turned on and off every 20 seconds. This can be clearly seen in the concentration analysis of the diffusion battery data. Again, the graph on top shows the voltages of the 5 stages, while the graph below shows the concentrations of the two modes.

15 To conclude, we have shown that the diffusion battery has some strong points: it has a good time resolution (about 2 seconds, given by the time constant of the ampèremeters), it is reasonably accurate for monomodal size distributions when compared with an SMPS, it can also detect a bimodal size distribution, it is much smaller and lighter than an SMPS or an ELPI. The software can run concurrently with the aerosol instrument manager of TSI to make simultaneous SMPS/diffusion battery measurements with a single computer.

16 The weak points of the diffusion battery are its relatively low sensitivity; it needs minimal concentrations of 10^3-10^4 particles/ccm to work, depending on the particle size. It has a small dynamic range of about 10^3, and the size range of particles that can be measured is limited to particles smaller than 200 nm. The diffusion battery grids must be cleaned regularly to avoid clogging.

17 To summarize, we believe that the electrical diffusion battery may be a good instrument for all those of you who want to measure size distributions with high time resolution but with only a rough size resolution.

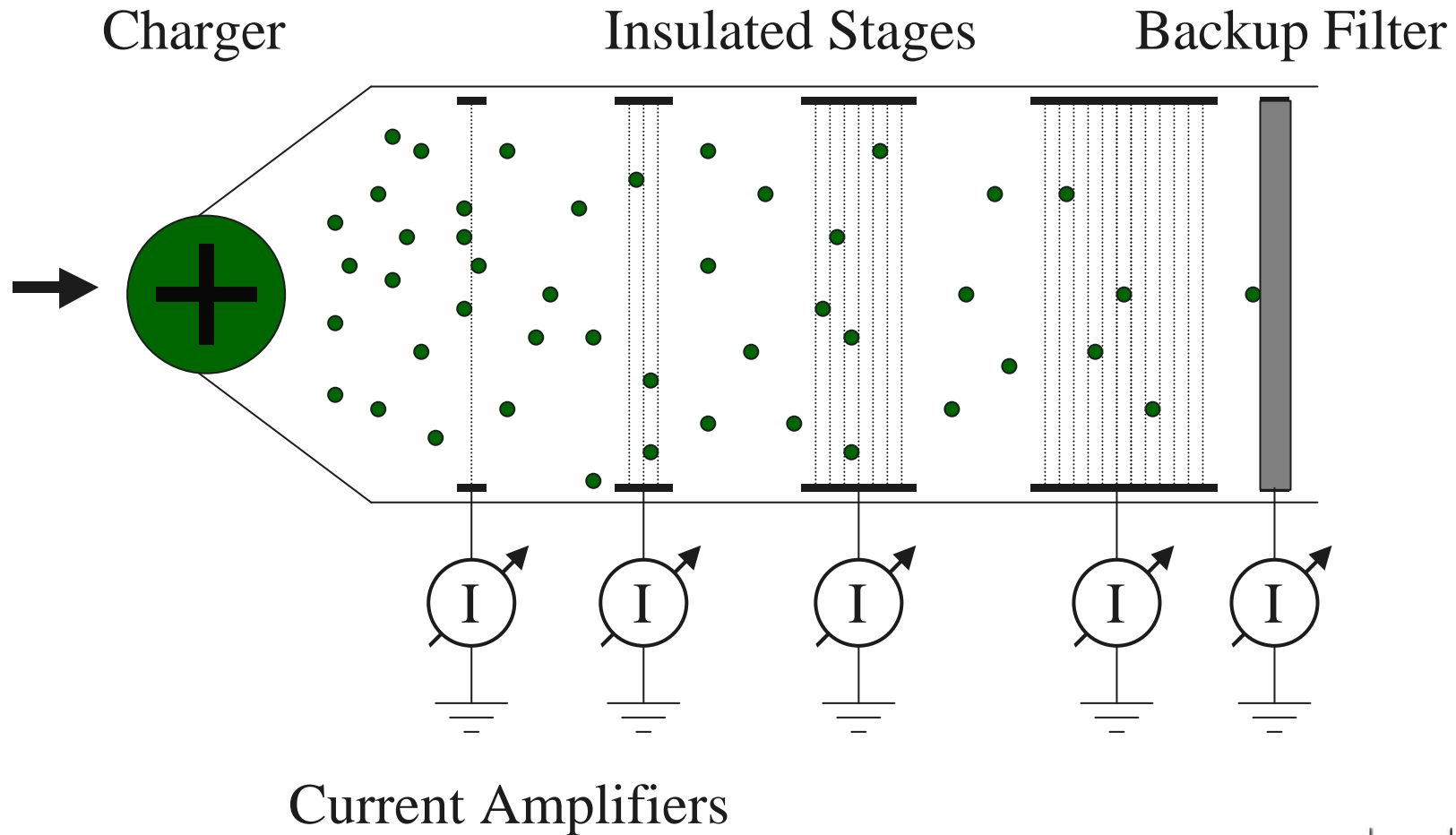# The Electrical Diffusion Battery
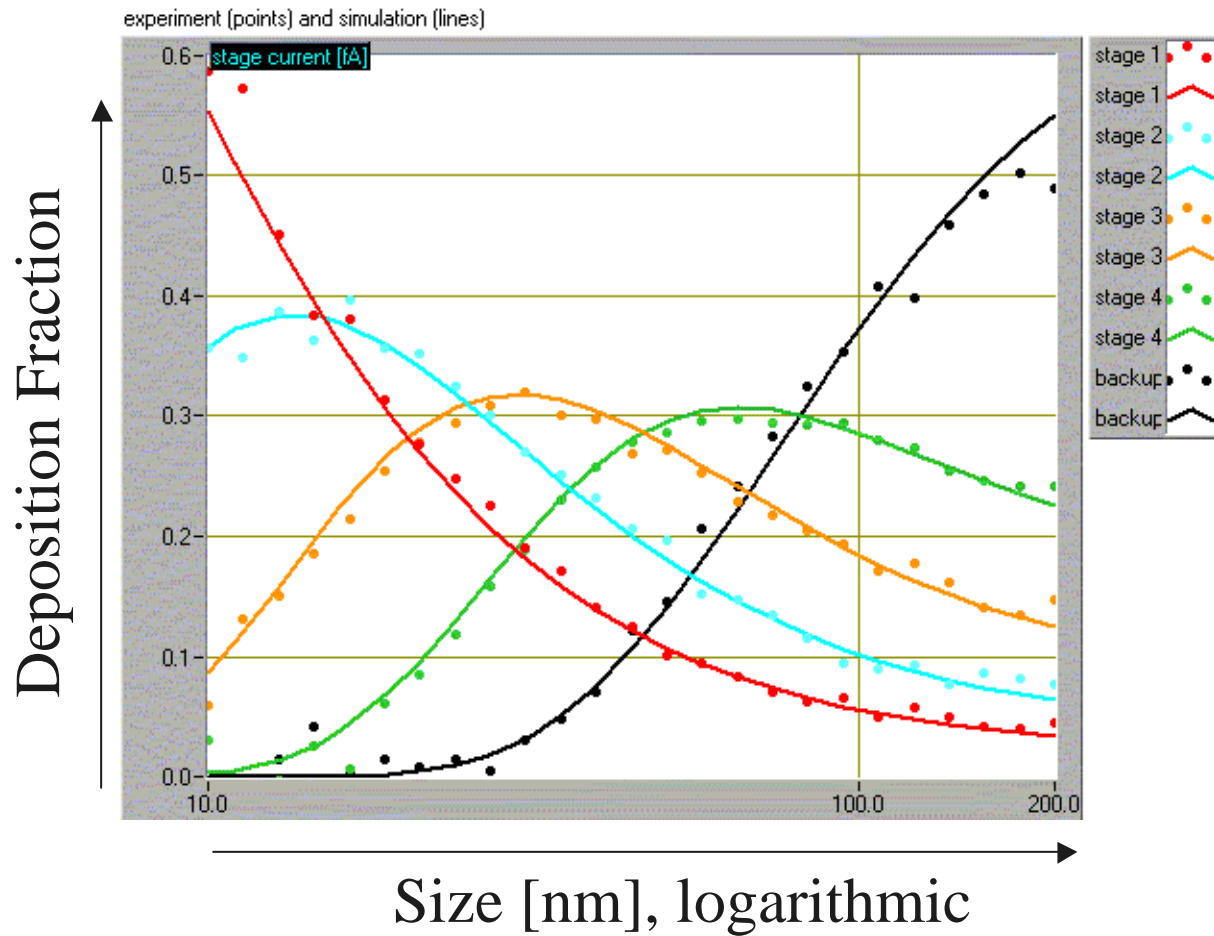
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Motivation

An ideal aerosol instrument would...

- Be able to measure the total concentration
- Be able to measure the size distribution
- Have a good time resolution
- Give information on the aerosol chemistry
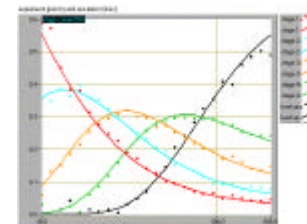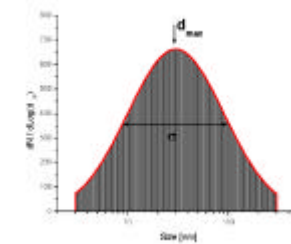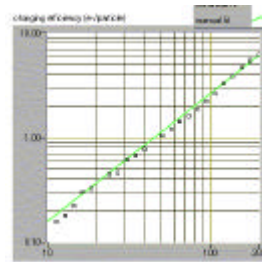- Be lightweight, portable and cheap

The Electrical Diffusion Battery

Charger

Insulated Stages

Backup Filter

Current Amplifiers

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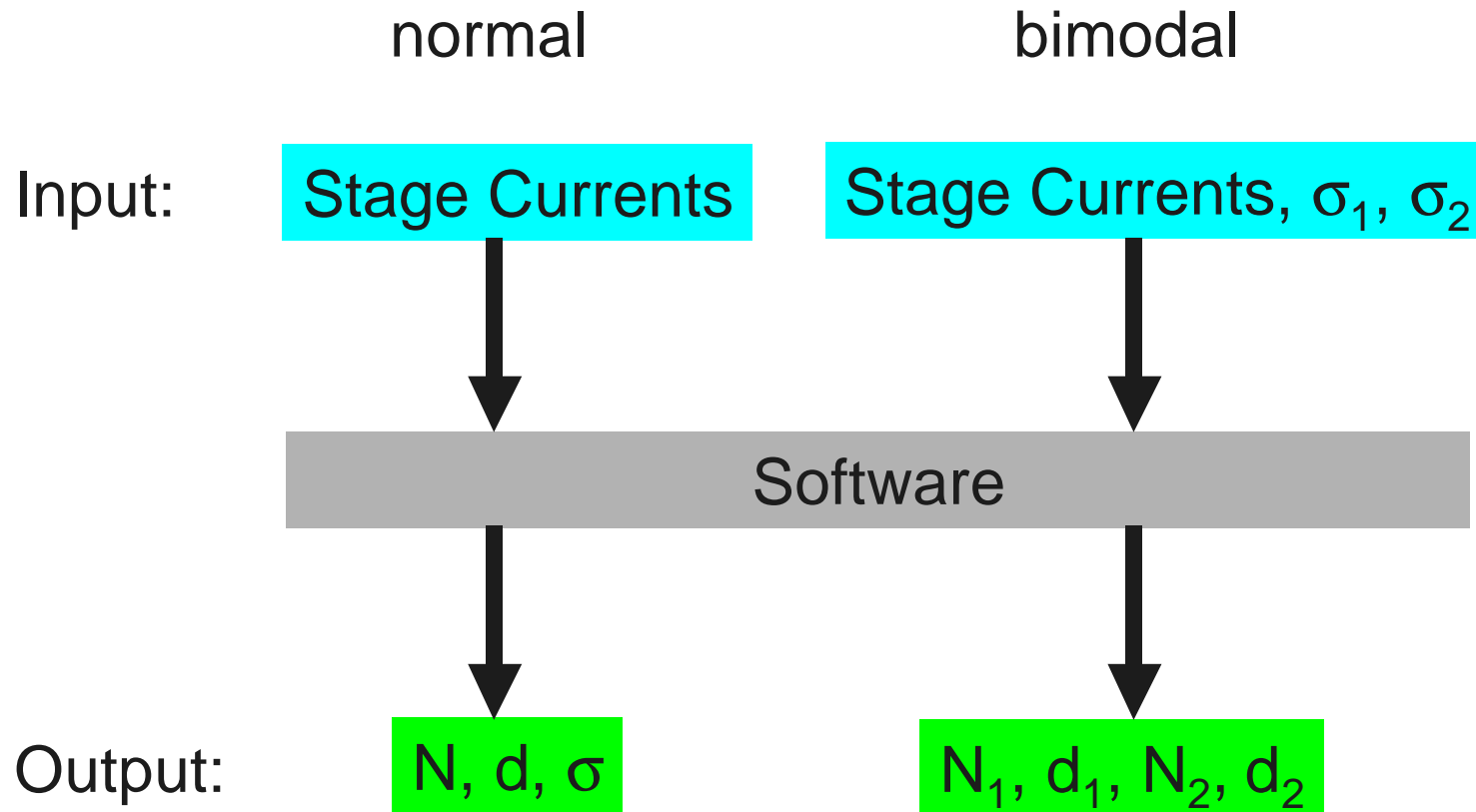Nordwestschweiz

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Monodisperse: Experiment

Calculating the Currents for „real" Aerosols

- Assume a size distribution: Lognormal

- Measure the charger efficiency

- Measure deposition fraction

$(N, d, \sigma) \Rightarrow$ stage currents
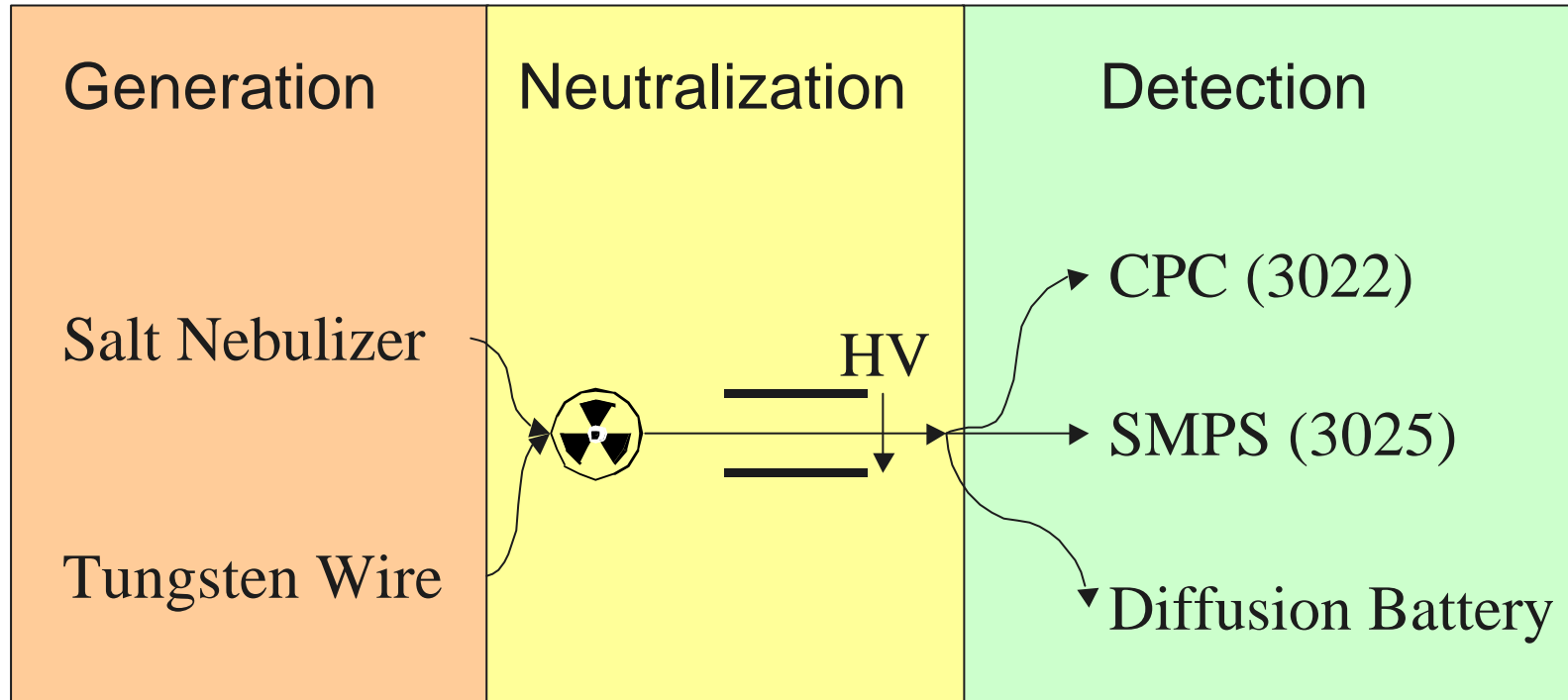
Data Inversion

normal   bimodal

Input: Stage Currents   Stage Currents, σ_1, σ_2

Software

Output: N, d, σ N_1, d_1, N_2, d_2

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Does it work?

Compare Diffusion Battery data with SMPS and CPC in 3 Experiments:

- „Lognormal" Aerosol
- Bimodal Aerosol
- Time-varying bimodal Aerosol

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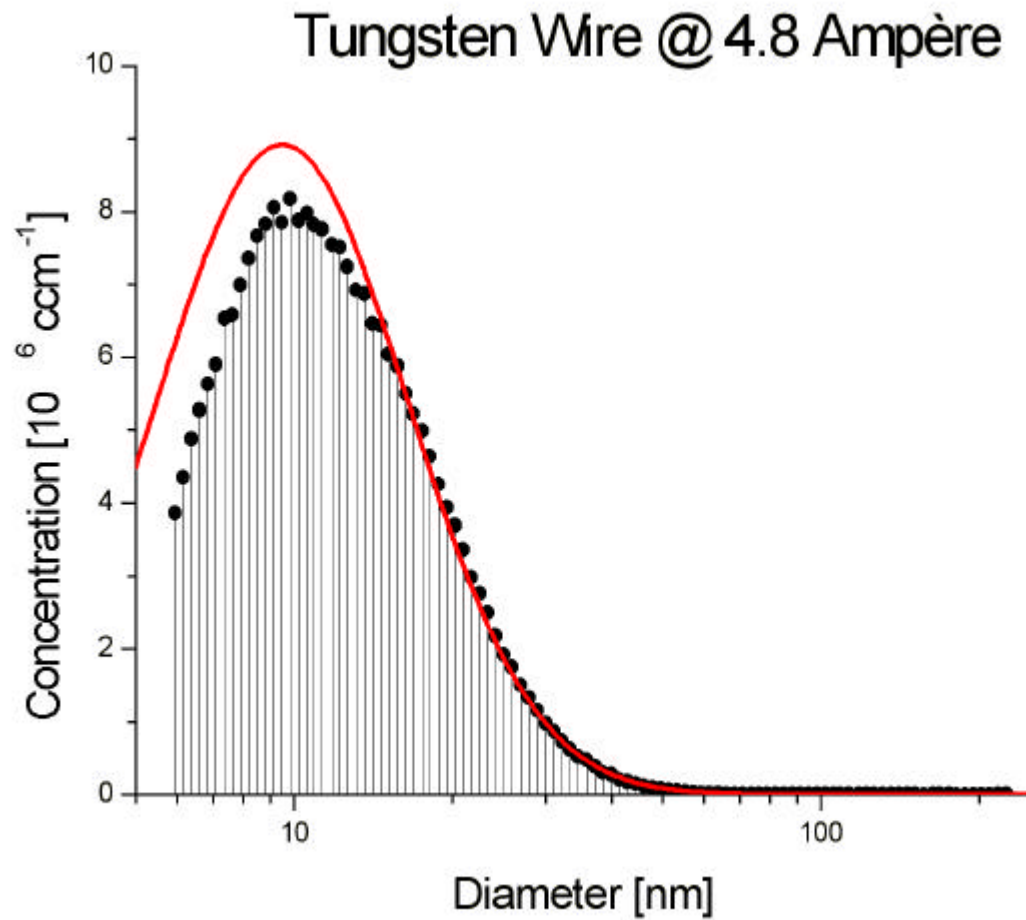Nordwestschweiz

Experimental Setup

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„Lognormal" Experiment

Description	SMPS			DB			CPC
	N	| d |	σ	N	| d |	σ	N
Wire 4.8A	3.9	| 10 |	1.53	5.2	| 9.5 |	1.73	2.85
Wire 5.2A	1.17	| 29 |	1.94	1.16	| 29 |	1.97	1.7
Salt Spray	0.98	| 50 |	1.86	0.90	| 68 |	1.78	1.3

[N] : 10^6/ccm, [d] : nm

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Comparison SMPS – DB I

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Comparison SMPS – DB II

Comparison SMPS – DB III

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Bimodal Aerosol

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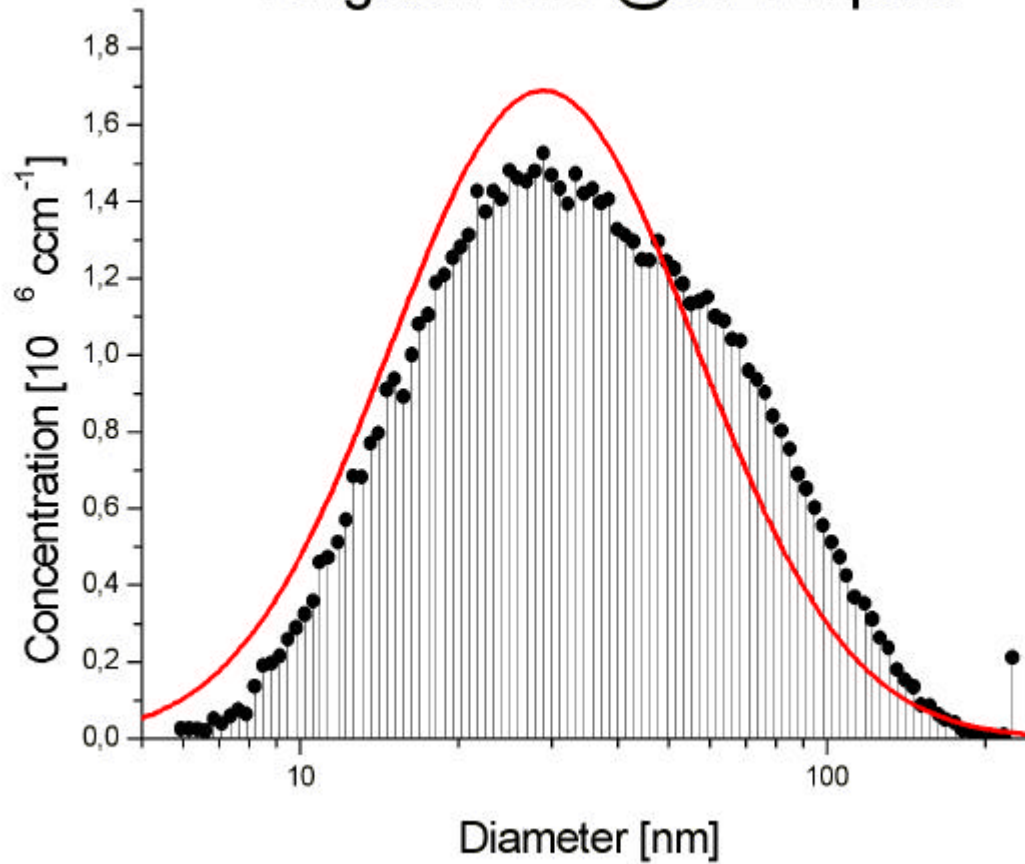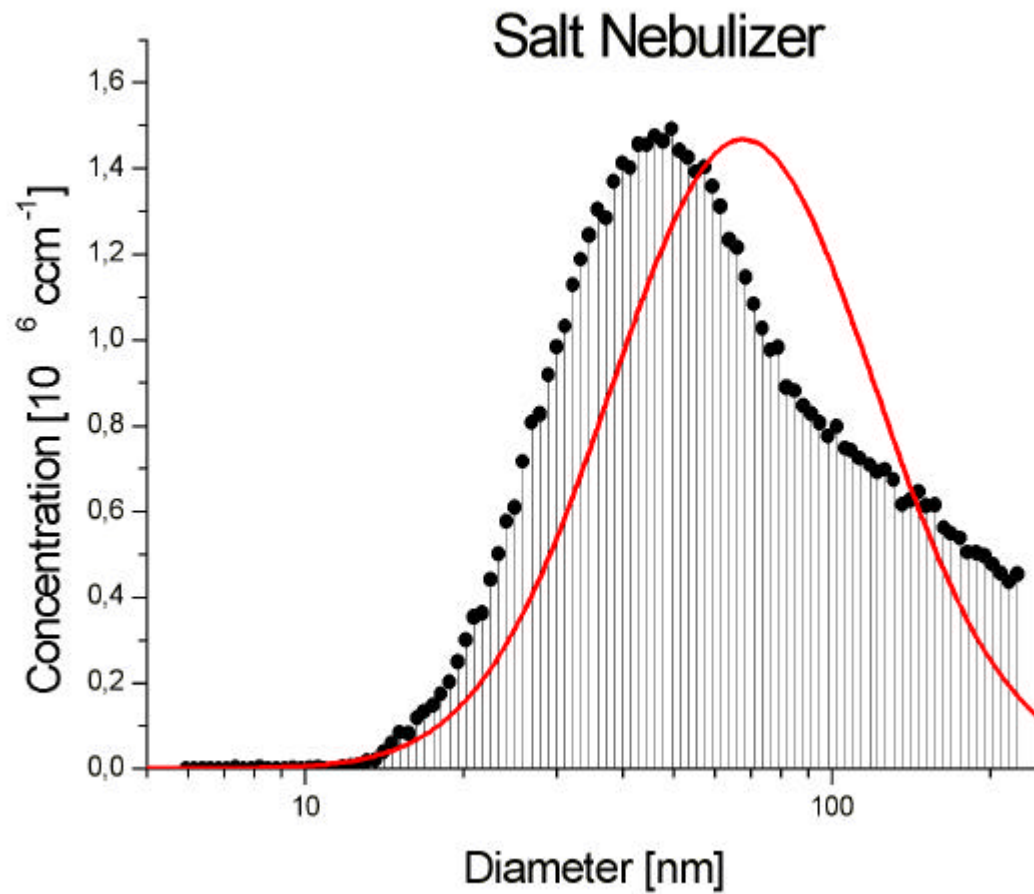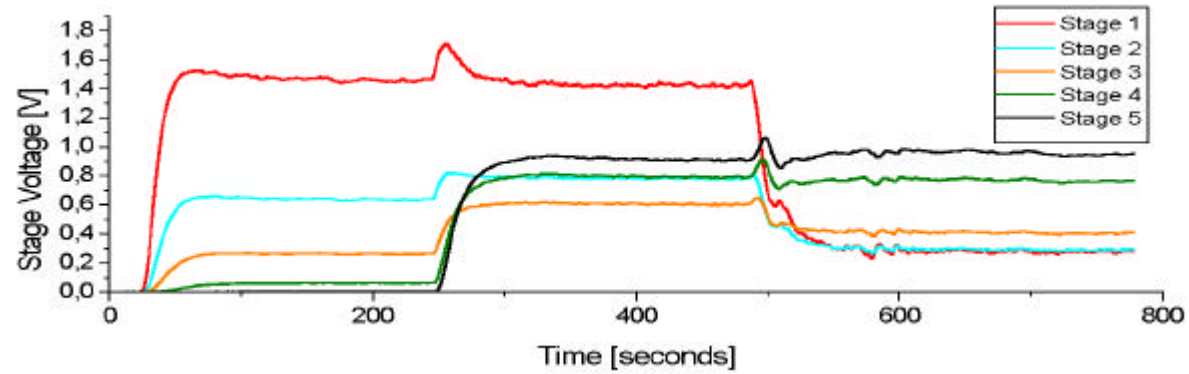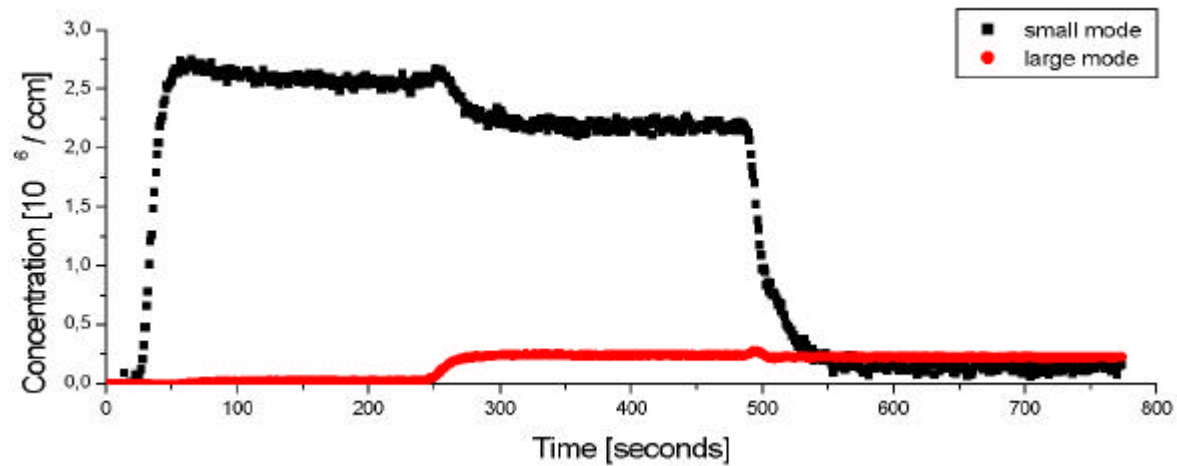
Bimodal: Comparison SMPS – DB II

Time-varying Bimodal

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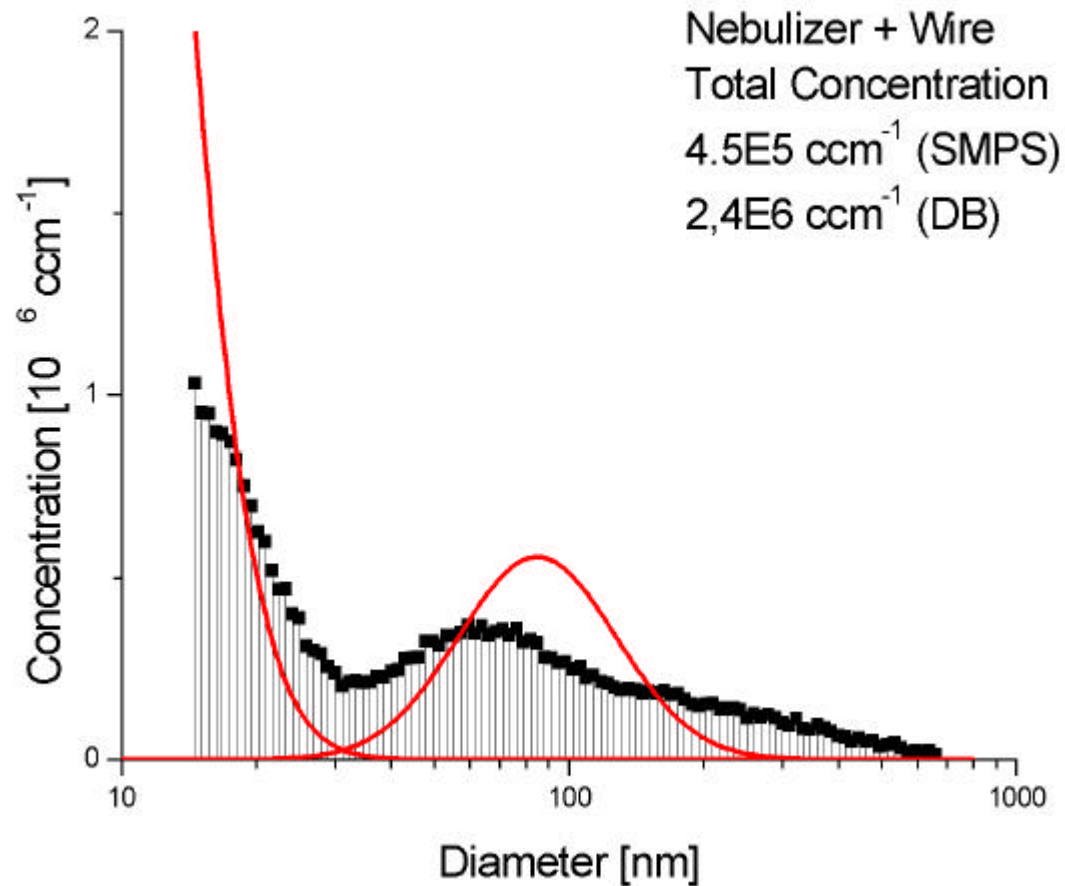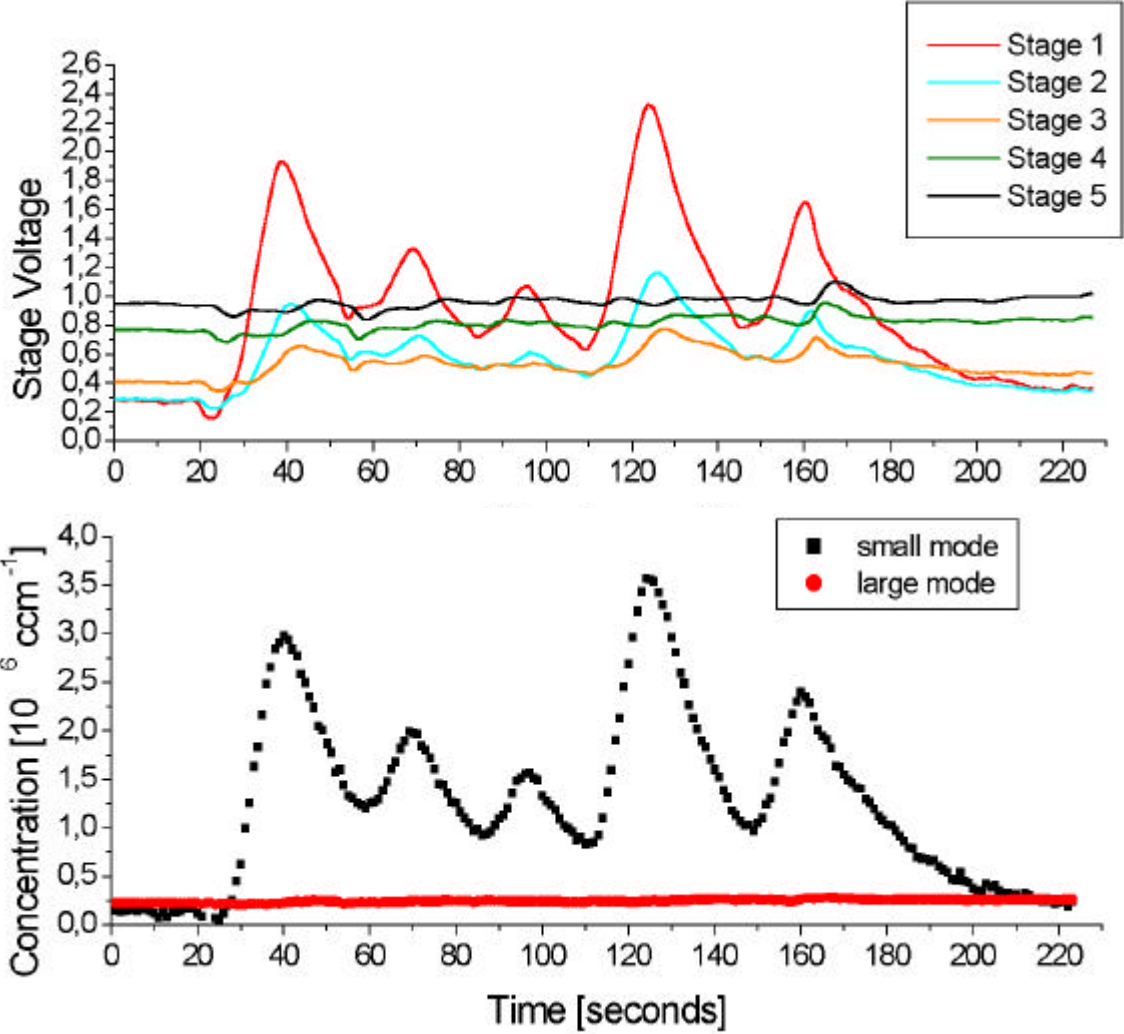
Conclusions: the good

The Diffusion Battery is...

- Fast (Time resolution: 2-3 seconds)
- Reasonably accurate
- Can detect bimodal aerosol
- Small & light
- No additional pumps needed
- Software can run concurrently with SMPS software

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Conclusions: the bad

Compared to an SMPS, the Diffusion Battery

- Has a low sensitivity ($10^3 - 10^4$ ccm^{-1})
- Has a small dynamic range (~10^3)
- Has a restricted size range (5-200 nm)
- Needs regular cleaning

Summary

As most instruments, the electrical diffusion battery has its strengths and weaknesses. If you are looking for an instrument which can give you a rough size distribution with a good time resolution, it might be a good choice.

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Acknowledgements

- Financing: Nanomet (BUWAL, SUVA, AUVA), FHA
- Industrial Partners: Matter Engineering
- Collaborators: Heinz Burtscher and Leo Scherrer

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