Accurate measurement of nanoparticle charge, number and size with the ELPI+™ instrument

Erkki Lamminen
Osuusmyllynkatu 13, 33700 Tampere, Finland
E-mail: erkki.lamminen@dekati.fi

Abstract. Nanoparticle characterization is mainly carried out by microscopy techniques and measurements of size and concentration. However, in order to comprehensively understand the behavior of the aerosol, information on particle charge level is critical. Particle charge has a major effect on the coagulation, deposition and transport as well as on the health effects of the particles. While aged aerosols generally are mainly neutral in terms of charge, freshly generated or resuspended particles can have high charge levels that vary depending on the size, material and generation method of the particles. Charging processes for particles are problematic as they are usually both time dependent and material dependent with sudden changes in magnitude. This makes the charge of a particle nearly impossible to predict without detailed studies and direct measurements. ELPI+™ instrument is a completely new aerosol measurement instrument based on the widely used Electrical Low Pressure Impactor (ELPI) technique. ELPI+™ measures particle concentration and size in a wide size range from 6 nm to 10 µm in real-time. The operation is based on first charging the particles in a corona charger and then size segregating them in a cascade impactor where all impactor stages are electrically insulated. With the ELPI+™ instrument it is possible to measure not only the particle size and concentration in real-time, but also the charge distribution of the particles. As the particle size classification is made with an impactor, the measured particles can be subsequently analyzed if needed with a suitable technique.

1. Introduction

Effective use of nanoparticles in industry benefits from thorough understanding of the processes that affect the particle transformation, transport and deposition while in aerosol form. These processes are governed mainly by particle size, concentration and shape. Freshly generated nanoparticles, especially in the case of high temperature processes or burst generation, may carry an electrical charge. This charge may have a significant effect on the behavior of the formed aerosol.

Charging processes during particle generation are sensitive to particle material, temperature, humidity. In the case of burst generation processes there may be build-up and release effects that have a significant effect on the generated particle charge level. The magnitude and/or polarity of the charge is generally very difficult to predict even if the initial conditions before are well known. Therefore in order to be able to estimate the effect of the charge it is beneficial to be able to make a direct measurement of the charge.

Electrical Low Pressure Impactor+ (ELPI+™, Dekati Ltd.) measures particle size and concentration with a dynamic range. In addition ELPI+™ is capable to measure the charge distribution...
in real-time and to carry out charge per number or charge per mass (Q/N, Q/M) measurement automatically.

In this work we first discuss the effect of charge on nanoparticle behavior and then present the features and specifications of the ELPI+™ instrument.

2. Effect of charge on nanoparticles
This chapter describes the effects of charge on nanoparticle behavior.

2.1. Coagulation
When two aerosol particles come into contact with each other, generally the particles become attached. This process thus reduces particle concentration, while increasing particle size. Mass concentration is not affected by this process and while the total surface area of the population decreases slightly, surface area of single particles increases significantly. Coagulation occurs in all aerosol populations and is highly dependent on aerosol concentration and on the width of the aerosol size distribution. High aerosol concentration and a large spread in particle sizes enhance coagulation.

If an aerosol population is charged it has a significant effect on the coagulation process [1]. In the case of both positive and negative particles present in an aerosol, coagulation is enhanced [2] and resulting particle size distribution is narrower than in the case of neutral aerosol. If the aerosol contains mainly particles charged by single polarity, coagulation is slowed down.

Depending on the charge state of the aerosol, coagulation may either be enhanced or slowed down. This will cause a generated aerosol to have a different number concentration, size and surface properties depending on the charge attained during the generation or dispersion process.

2.2. Space charge effect
A cloud of generated particles expands due to mixing with surrounding gas and diffusion. If the particles are charged mainly with one polarity, the cloud of particles will expand more rapidly. This effect therefore reduces the concentration of particles in a specific volume compared to uncharged particles.

Space charge may have a significant effect also on losses, if a high concentration of charged particles is transported via a transfer line. Space charge effect will cause the particles to move towards the sampling line walls due to expansion of the cloud, hence there is a high chance of deposition on the walls. If the charge state of the generated aerosol changes and the aerosol is transferred through a line, the transfer efficiency will also change.

2.3. Deposition
Charged particles move in an electric field according to their charge level and according to field strength. This electrostatic force is usually significant compared to other forces acting upon particles in an aerosol.

Electrostatic force is especially important when charged particles are transferred in lines. The transfer lines must be constructed of conductive material. Insulated lines can easily become statically charged and essentially turn into electrostatic precipitators that remove charged particles. In addition to transfer lines, any space with an electric field will have a significant effect on the movement of charged particles.

3. Measurement of particle charge
This chapter includes the operation principle, specifications and features of the ELPI+™ instrument and describes how charge and charge/number measurements are carried out.

3.1. ELPI+™ operation principle
The ELPI+™ operating principle can be divided into three major parts: particle charging, size classification in a cascade impactor and electrical detection with sensitive electrometers. The particles
are first charged into a known charge level in the corona charger. After charging, the particles enter a cascade low pressure impactor with 14 electrically insulated collection stages. The particles are collected in the different impactor stages according to their aerodynamic diameter, and the electric charge carried by particles into each impactor stage is measured in real time by sensitive electrometers. This measured current signal is directly proportional to particle number concentration and size. The particle collection into each impactor stage is dependent on the aerodynamic size of the particles. Measured current signals are converted to particle size distribution using particle size dependent relations describing the properties of the charger and the impactor stages. The result is particle number concentration and size distribution in real-time. ELPI+™ operation principle is shown in Figure 1.

![Figure 1. ELPI+™ operation principle](image-url)
3.2. ELPI+™ specifications
ELPI+™ specifications are given in Table 1.

| Table 1. ELPI+™ Specifications |
|-------------------------------|
| **Measurement**               |
| Nominal air flow              | 10lpm                         |
| Particle size range           | 0.006–10µm                    |
| Number of size channels       | 14                            |
| Sampling rate                 | 10Hz                          |
| **Operation conditions, instrument** |
| Ambient temperature           | 5–35°C                        |
| Ambient humidity              | 0–90%, non condensing         |
| **Sample conditions**         |
| Gas temperature               | < 50°C                        |
| **Dimensions**                |
| Weight                        | 22kg                          |
| Dimensions                    | 400 x 420 x 220 (mm)          |
| **Electrical specifications** |
| Electric power                | 100-250V, 50-60Hz, 200W        |
| Charger voltage               | 3.5kV                         |
| Charger current               | 1µA                           |
| **Computer specifications**   |
| Optional Connection to ELPI+™| RS-232 serial (USB–RS-232 adapter provided with the ELPI+™ instrument), or Ethernet |

**Nominal impactor specifications for ELPI+™ impactor**

| Stage | D50% [µm] | Di [µm] | Number min [1/cm³] | Number max [1/cm³] | Mass min [µg/m³] | Mass max [mg/m³] |
|-------|-----------|---------|--------------------|--------------------|------------------|------------------|
| 15    | 10        |         |                    |                    |                  |                  |
| 14    | 6.800     | 8.4     | 0.10               | 2.4E+04            | 30               | 10000            |
| 13    | 4.400     | 5.3     | 0.10               | 2.4E+04            | 10               | 3000             |
| 12    | 2.500     | 3.2     | 0.15               | 5.4E+04            | 3.0              | 1000             |
| 11    | 1.600     | 2.0     | 0.3                | 1.1E+05            | 1.4              | 450              |
| 10    | 1.000     | 1.3     | 0.5                | 1.9E+05            | 0.7              | 210              |
| 9     | 0.640     | 0.810   | 1                  | 3.5E+05            | 0.3              | 100              |
| 8     | 0.400     | 0.510   | 2                  | 6.4E+05            | 0.1              | 50               |
| 7     | 0.260     | 0.330   | 3                  | 1.2E+06            | 0.07             | 20               |
| 6     | 0.170     | 0.210   | 5                  | 2.1E+06            | 0.03             | 10               |
| 5     | 0.108     | 0.140   | 10                 | 3.7E+06            | 0.02             | 5                |
| 4     | 0.060     | 0.081   | 20                 | 7.3E+07            | 0.005            | 2                |
| 3     | 0.030     | 0.042   | 50                 | 1.7E+07            | 0.002            | 0.5              |
| 2     | 0.017     | 0.022   | 100                | 3.4E+07            | 0.001            | 0.25             |
| 1     | 0.006     | 0.01    | 250                | 8.3E+07            | 0.0004           | 0.13             |
The min and max values given in Table 1 are calculated assuming 1.5 fA and 400 000 fA current measured per stage. Please refer to Appendix A for a detailed description on the ELPI+ calculation procedure. D50% is the aerodynamic equivalent size for an impactor stage at which 50% of the particles are collected. Di is the geometric midpoint of the stage collection range.

3.3. ELPI+™ features

ELPI+™ enables measurement of real-time particle size distribution and concentration in the size range of 6nm - 10μm with 10Hz acquisition rate. ELPI+™ is based on well-known ELPI™ technology [3-5]. This allows the measurement of a wide particle size spectrum with a single device for different studies. The ELPI+™ features also include stand-alone operation, wide sample concentration range and robust structure for operation even in harsh conditions. The use of impactor technology for size classification of particles enables post-measurement chemical analysis of the collected particles.

There has been a great deal of interest in the nanotechnology community for measurement of aerosol particles via particle charging and detection of charged particles. ELPI+™ also provides a detailed measurement of this via the direct electrometer current readings with added accurate impactor size classification.

3.4. Measurement of particle charge with ELPI+™

ELPI+™ measures the particle concentration by charging particles with a unipolar charger and then size classifying the particles with an impactor into individual size bins, from which electrometers continuously measure currents. Particle charge measurements are carried out by simply turning the unipolar charger off and reading the electrometer currents. With this measurement we know the total amount of charge in each size bin in real-time. This allows detailed monitoring of the particle charge in the size range from 6 nanometers to 10 micrometers.

Charge/number and charge/mass (Q/N and Q/M) are interesting quantities which give the number of elementary charges per particle or per mass. Measurement of Q/N gives detailed information on the charging state of particles and takes into account changes both in carried charge and particle concentration. ELPI+™ measures the average number of elementary charges per number of particles or mass by switching the charger unit on and off for defined periods of time in the order of 3-5 seconds. The ELPI+™ measurement gives the charge averaged for all particles in the measurement channel and hence cannot take into account possible differences in case two particles in the measurement channel carry a different amount of elementary charges. The measured quantity will also differ from Q/N if there are both positively and negatively charged particles present in a measurement channel. In this case the ELPI+™ measurement gives the resulting net charge/particle per measurement channel. During the measurement period the aerosol must remain stable in terms of concentration and size to gain reasonable results. Based on the measurements, ELPI+™ software automatically calculates Q/N and Q/M as a function of particle size. An example of measured Q/N data of particles charged with a commercial diode charger is presented in Figure 2.
4. Conclusions.
Electrical charge can have a major effect on nanoparticle behaviour and may influence particle number, size and surface area. Due to the high dependence of charge on materials and conditions, it is necessary to measure the charge level to be able to take the effect into account.

ELPI+™ instrument is capable of measuring particle number concentration, size distribution and particle charge in real time, which makes it an ideal tool for nanoparticle research including charge studies.

References
[1] Shahub, A. M. and M. M. R. Williams. Brownian Collision Efficiency. *J. Physics: D, Applied Physics, 21*:231 (1988)
[2] Friedlander, S. K. Smoke, Dust, and Haze, 2nd Ed. Oxford University Press (2000)
[3] Keskinen, J., Pietarinen, K. and Lehtimäki, M. (1992) Electrical Low Pressure Impactor, *J. Aerosol Sci. 23*, 353-360
[4] Marjamäki, M., Keskinen, J., Chen, D-R. and Pui, D. Y. H. (2000) Performance Evaluation of the Electrical Low-Pressure Impactor (ELPI), *Journal of Aerosol Science 31*:2, pp. 249-261
[5] Yli-Ojanperä, J., Kannosto, J., Marjamäki, M. & Keskinen. J. 2010. Improving the Nanoparticle Resolution of the ELPI. *Aerosol and Air Quality Research, vol 10*, pp. 360-366

Figure 2. ELPI+™ Q/N measurement result as a function of aerodynamic diameter
Appendix A
This section contains an example of ELPI+calculation from current values to selected distribution. Note that this calculation does not consider small particle correction. Only the calculation from current values to aerosol size distribution is presented.

Few things have to be known before it is possible to calculate selected distribution from current values:

**Impactor:** Aerodynamic D50% values (see impactor data sheet)
Flowrate (see impactor data sheet)

**Charger:** Efficiency curve (PneQ) (see ELPI+TM data sheet)

**Particles:** Density
Is Aerodynamic or Stokes diameter wanted

**ELPI+TM:**
Current values
Dilution factor

**Used symbols:**

- $D_p$ \textsuperscript{a} Particle aerodynamic diameter
- $D_p$ \textsuperscript{s} Particle stokes diameter
- $D_i$ \textsuperscript{a} Geometric mean of a channel (Aerodynamic diameter)
- $D_i$ \textsuperscript{s} Geometric mean of a channel (Stokes diameter)
- $C_{c_a}$ Cunningham’s slip correction vector for aerodynamic particle size
- $C_{c_s}$ Cunningham’s slip correction vector for stokes particle size
If we assume that the following startup values are used:

| Impactor properties | 1  | 2  | 3  | 4  | 5  | 6  | 7  | 8  | 9  | 10 | 11 | 12 | 13 | 14 | 15 |
|---------------------|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|
| Aerodynamic \(D_p, [\mu m]\) | 0.006 | 0.017 | 0.03 | 0.06 | 0.108 | 0.17 | 0.26 | 0.4 | 0.64 | 1 | 1.6 | 2.5 | 4.4 | 6.8 | 10 |

| Charger efficiency function |
|-----------------------------|
| Mult1 | 5.941 |
| Exp1 | 1.637 |
| Limit1 | 0.0239 |
| Mult2 | 1.819 |
| Exp2 | 1.3201 |
| Limit2 | 10 |
| Mult3 | 1.819 |
| Exp3 | 1.3201 |

| Impactor type |
|---------------|
| Impactor | 10045 |
| Flowrate | 10 |
| Density | 1 |
| Dilution | 1 |

Then Cunningham’s slip correction factor is calculated using equation

\[
C_{Ca} = 1 + \left(\frac{2}{76 * D_{p_a}}\right)^6(6.32 + 2.01 * e^{-0.1095 * 76 * D_{p_a}}) \text{ for each D50% value (76=pressure in cmHg)}
\]

Now we have the Cunningham’s slip correction factor for each D50% value:

| Impactor properties | 1  | 2  | 3  | 4  | 5  | 6  | 7  | 8  | 9  | 10 | 11 | 12 | 13 | 14 | 15 |
|---------------------|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|
| Aerodynamic \(D_p, [\mu m]\) | 0.006 | 0.017 | 0.03 | 0.06 | 0.108 | 0.17 | 0.26 | 0.4 | 0.64 | 1 | 1.6 | 2.5 | 4.4 | 6.8 | 10 |
| \(C_{Ca}\) | 37.1057 | 13.4843 | 7.9175 | 4.3070 | 2.7393 | 2.0539 | 1.6631 | 1.4205 | 1.2603 | 1.1663 | 1.1039 | 1.0665 | 1.0378 | 1.0245 | 1.0166 |

We calculate also geometric mean of each channel, which is called \(D_i\) (\(D_{i,n}\) equals \(D_i\) of channel \(n\))

\[
D_{i,n} = \sqrt{D_{p,n} * D_{p,n+1}}
\]

| Impactor properties | 1  | 2  | 3  | 4  | 5  | 6  | 7  | 8  | 9  | 10 | 11 | 12 | 13 | 14 | 15 |
|---------------------|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|
| Aerodynamic \(D_p, [\mu m]\) | 0.006 | 0.017 | 0.03 | 0.06 | 0.108 | 0.17 | 0.26 | 0.4 | 0.64 | 1 | 1.6 | 2.5 | 4.4 | 6.8 | 10 |
| \(C_{Ca}\) | 37.1057 | 13.4843 | 7.9175 | 4.3070 | 2.7393 | 2.0539 | 1.6631 | 1.4205 | 1.2603 | 1.1663 | 1.1039 | 1.0665 | 1.0378 | 1.0245 | 1.0166 |
| \(D_{i,n}\) | 0.0136 | 0.0226 | 0.0424 | 0.0805 | 0.1355 | 0.2102 | 0.3225 | 0.5060 | 0.8000 | 1.2649 | 2.0000 | 3.3166 | 5.4699 |

Next, we must find the same values for particle Stokes diameters. Iteration must be used to find out the stokes diameter.

\[
D_{p_s} = \frac{D_{p_a}}{\sqrt{Density * \frac{C_{Ca}}{C_{Ca}^2}}}
\]

Where \(C_{Ca}\) is again.
Now we have the following values for the impactor stages:

\[ C_{Cs} = 1 + \left( \frac{2}{76 \cdot Dp_s} \right) \ast (6.32 + 2.01 \times e^{-0.1095 \cdot 76 \cdot Dp_s}) \]

At this point we have to decide if aerodynamic or stokes particle size is used. Let’s assume that it is aerodynamic:

Then, we calculate a dlogDp multiplier vector

\[ dlogDp = \log_{10} \frac{Dp_{n+1}}{Dp_n} \]
Finally, we calculate the conversion vector $X$ from current to number. Now we need the charger efficiency function.

Charger efficiency function is a three-part power fit and it is a result of calibration values $P*n$ and constants $e$ and $Q$ where:

- $P =$ Charger penetration
- $n =$ average charge per particle
- $e =$ elementary charge ($1.602 \times 10^{-19} \text{ C}$)
- $Q =$ Calibration flow rate (10 lpm)

$P*n$ values are originated from article Marjamäki, M., Keskinen, J., Chen, D-R. and Pui, D. Y. H. (1999) Performance Evaluation of the Electrical Low-Pressure Impactor (ELPI), Journal of Aerosol Science 31 (2) (2000) pp. 249-261.

Giving us the efficiency function:

$$
\begin{align*}
\text{Di} < 0.095 \mu \text{m}: & \quad X(\text{Di}) = 4.48\text{Di}^{1.9087} \\
0.095 \mu \text{m} < \text{Di} < 1.196: & \quad X(\text{Di}) = 1.293\text{Di}^{1.3805} \\
\text{Di} > 1.196 \mu \text{m}: & \quad X(\text{Di}) = 1.3529\text{Di}^{1.1308}
\end{align*}
$$

The charger efficiency curve is calibrated using flowrate of 10 lpm, so we must reduce the efficiency curve to a real flow.

For example, stage 1: $\text{Di}_s=0.0291$ (less than 0.095), Flow rate = 9.71, Charger efficiency as above:

$$
X = 4.48 \times \text{Di}^{1.9087} \times \frac{\text{Flowrate}}{\text{Calibration flow}} = 4.48 \times 0.0291^{1.9087} \times \frac{9.71}{10}
$$

Note that Stokes $\text{Di}$ is used, because the charging process is dependent on the particles stokes diameter. That’s why it is always necessary to estimate the particle density and calculate the particle stokes diameter.
We are able to form all conversion vectors:

| Impactor properties | 1  | 2  | 3  | 4  | 5  | 6  | 7  | 8  | 9  | 10 | 11 | 12 | 13 | 14 | 15 |
|---------------------|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|
| Aero-dynamic Dp, [µm] | 0.006 | 0.017 | 0.03 | 0.06 | 0.108 | 0.17 | 0.26 | 0.4 | 0.64 | 1  | 1.6 | 2.5 | 4.4 | 6.8 | 10 |
| Stokes Cc, Di | 37.1057 | 13.4843 | 4.3070 | 2.7393 | 2.0539 | 1.6631 | 1.4205 | 1.2603 | 1.1039 | 1.0665 | 1.0378 | 1.0245 | 1.0166 |   |
| Dp, [µm] | 0.0136 | 0.0226 | 0.0424 | 0.0805 | 0.1355 | 0.2102 | 0.3225 | 0.5060 | 0.8000 | 1.2649 | 2.0000 | 3.3166 | 5.4699 | 8.2462 |   |
| Di | 0.006 | 0.017 | 0.03 | 0.06 | 0.108 | 0.17 | 0.26 | 0.4 | 0.64 | 1  | 1.6 | 2.5 | 4.4 | 6.8 | 10 |
| dlogDp | 0.4523 | 0.2467 | 0.3010 | 0.2553 | 0.1970 | 0.1845 | 0.1871 | 0.2041 | 0.1938 | 0.2041 | 0.1938 | 0.2455 | 0.1891 | 0.1675 |   |
| X, fAcc | 0.0052 | 0.0120 | 0.0281 | 0.0654 | 0.1300 | 0.2321 | 0.4083 | 0.7400 | 1.3549 | 2.4806 | 4.5417 | 8.8553 | 17.1412 | 29.47 |

We are able to form all conversion vectors:

| Conversion Vector | Equation |
|-------------------|----------|
| Number dN/dlogDp [1/cm³] | 1/X*1/dlogDp*Dilution |
| Diameter dD/dlogDp [µm/cm³] | 1/X*Di*1/dlogDp*Dilution |
| Area dA/dlogDp [µm²/cm³] | 1/X*Di² * π *1/dlogDp*Dilution |
| Volume dV/dlogDp [µm³/cm³] | 1/X*Di³ * π *(1/6)*1/dlogDp*Dilution |
| Mass dM/dlogDp [mg/m³] | 1/X*Di³ * π *(1/6)*Dilution*Density*0.001 |
| Number N [1/cm³] | 1/X*Dilution |
| Diameter D [µm/cm³] | 1/X*Di*Dilution |
| Area A [µm²/cm³] | 1/X*Di² * π *Dilution |
| Volume V [µm³/cm³] | 1/X*Di³ * π *(1/6)*Dilution |
| Mass M [mg/m³] | 1/X*Di³ * π *(1/6)*Dilution*Density*0.001 |
Now when we multiply the current values vector with these conversion vectors we get the selected distribution. For example consider the following values:

| Conversion vectors | 1   | 2   | 3   | 4   | 5   | 6   | 7   | 8   | 9   | 10  | 11  | 12  | 13  | 14  |
|-------------------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| Number dN/dlogDp [1/cm³] | 422.4522 | 337.9666 | 118.3627 | 59.9285 | 39.0460 | 23.3455 | 13.0898 | 6.6202 | 3.8080 | 1.9749 | 1.1360 | 0.4600 | 0.3086 | 0.2026 |
| Diameter dD/dlogDp [µm/cm³] | 5.7481 | 7.6324 | 5.0217 | 4.8241 | 5.2907 | 4.9081 | 3.3496 | 3.0464 | 2.4981 | 2.2720 | 1.5255 | 1.6879 | 1.6706 |
| Area dA/dlogDp [µm²/cm³] | 0.2457 | 0.5415 | 0.6693 | 1.2200 | 2.2522 | 3.2417 | 4.2768 | 5.3243 | 7.6565 | 9.9271 | 14.2754 | 15.8952 | 29.0054 | 43.2800 |
| Volume dV/dlogDp [µm³/cm³] | 0.0006 | 0.0020 | 0.0047 | 0.0164 | 0.0509 | 0.1136 | 0.2299 | 0.4490 | 1.0209 | 2.0928 | 4.7585 | 8.7864 | 26.4429 | 59.4826 |
| Mass dM/dlogDp [mg/m³] | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0001 | 0.0002 | 0.0004 | 0.0010 | 0.0021 | 0.0048 | 0.0088 | 0.0264 | 0.0595 |
| Number N [1/cm³] | 191.0741 | 83.3670 | 35.6307 | 15.2981 | 7.6930 | 4.3078 | 2.4489 | 1.3513 | 0.7381 | 0.4031 | 0.2202 | 0.1129 | 0.0583 | 0.0339 |
| Diameter D [µm/cm³] | 2.5998 | 1.8827 | 1.5117 | 1.2315 | 1.0424 | 0.9057 | 0.7898 | 0.6837 | 0.5905 | 0.4404 | 0.3745 | 0.3191 | 0.2798 |
| Area A [µm²/cm³] | 0.1111 | 0.1336 | 0.2015 | 0.3114 | 0.4437 | 0.5982 | 0.8001 | 1.0868 | 1.4840 | 2.0263 | 2.7669 | 3.9025 | 5.4837 | 7.2490 |
| Volume V [µm³/cm³] | 0.0003 | 0.0005 | 0.0014 | 0.0042 | 0.0100 | 0.0210 | 0.0430 | 0.0916 | 0.1979 | 0.4272 | 0.9223 | 2.1572 | 4.9992 | 9.9628 |
| Mass M [mg/m³] | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |

Now we multiply the current values vector with these conversion vectors we get the selected distribution. For example consider the following values:

| Conversion vector from current to number distribution (dN/dlogDp) from above | 1   | 2   | 3   | 4   | 5   | 6   | 7   | 8   | 9   | 10  | 11  | 12  | 13  | 14  |
|--------------------------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| Diameter D [µm/cm³]     | 585.69 | 1233.40 | 4571.91 | 12232.4 | 29672.2 | 36239.5 | 68540.1 | 80523.3 | 80747.2 | 44362.2 | 23538.5 | 8385.29 | 585.69 | 1233.40 |
| Number distribution (dN/dlogDp) | 422.4522 | 337.9666 | 118.3627 | 59.9285 | 39.0460 | 23.3455 | 13.0898 | 6.6202 | 3.8080 | 1.9749 | 1.1360 | 0.4600 | 0.3086 | 0.2026 |
| Number N [1/cm³]       | 247426 | 416848 | 541143 | 733069 | 1158580 | 846029 | 897176 | 533080 | 307485 | 87610 | 26739 | 3857 | 1404 | 621 |

And we get the number distribution.
Terms

Number distribution
Number distribution is formed by multiplying the current distribution with the conversion vector. 
\[dN] = [Ci] \times [(1/Xi(Di))] \]

1/dlog(Dp)
Aerosol distributions are normally given in the 1/dlog(Dp) mode. It is formed by dividing the stages measured value by the logarithmic width of the stage. In 1/dlog(Dp) mode the area of the histogram gives the value in each size range. 
\[dN/dlog(Dp)] = [dN] \times [(1/dlog(Dp))] \]

Diameter distribution
Diameter distribution gives the total diameter of all particles in each size range. It is formed by multiplying the current distribution by the conversion vector and by a vector formed from the midpoint values (Di) of each stage. 
\[dD/dlog(Dp)] = [Ci] \times [(1/Xi(Di))] \times [Di] \times [(1/dlog(Dp))] \]

Area distribution
Area distribution gives the total surface area of all particles in each size range. It is formed by multiplying the current distribution by the conversion vector and by a vector formed from the surface areas of spheres having diameter equal to midpoint values (Di) of each stage. 
\[dA/dlog(Dp)] = [Ci] \times [(1/Xi(Di))] \times [\pi \times Di^2] \times [(1/dlog(Dp))] \]

Volume distribution
Volume distribution gives the total volume of all particles in each size range. It is formed by multiplying the current distribution by the conversion vector and by a vector formed from the volumes of spheres having diameter equal to midpoint values (Di) of each stage. 
\[dV/dlog(Dp)] = [Ci] \times [(1/Xi(Di))] \times [\frac{1}{6} \times \pi \times Di^3] \times [(1/dlog(Dp))] \]

Mass distribution
Mass distribution gives the total mass of all particles in each size range. It is formed by multiplying the current distribution by the conversion vector and by a vector formed from the masses of spheres having diameter equal to midpoint values (Di) of each stage. Note that mass distribution is scaled to unit mg / m³. 
\[dV/dlog(Dp)] = [Ci] \times [(1/Xi(Di))] \times [\frac{1}{6} \times \pi \times Di^3 \times \text{Density}] \times [(1/dlog(Dp))] \times 10^{-3} \]