Aerosols in a nutshell: Nobody can escape it and it affects us all the time. Every day we inhale approx. 15,000 liters of air. Depending on the location we live in and the time of the year we are exposed to the effects of civilization in terms of sulfur- or nitric oxides, airborne particle matter and aromatic hydrocarbons. According to the WHO, about 7 million people die every year as a result of air-pollution related diseases. At first pollutants deposit in the deeper lung where they trigger bronchitis and even lung cancer. The smaller-sized pollution fraction even trespasses into the blood circulatory system drastically increasing the risk of heart attacks and strokes. Besides these known adverse effects, more hidden side-effects become evident that are attributable to air-pollution and include cancer pathologies outside the lungs, diabetes and epigenetic factors.

This lab-course material provides background information to aerosol dynamics, effects on climate and health. In addition it provides basic information on selected tools to measure and quantify aerosol inventories and how these data can be implemented into a computer code for lung deposition modeling. The core issue with air pollution: nobody can escape as it affects everyone. With a breathing turnover of 8.6kL a day (sedentary lifestyle at 12 Bpm, tidal volume 0.5L of an adult) and based upon the location we live in, we are exposed to the traces of civilization that include sulfur-, and nitrogen-oxides, ozone, particle matter as well as hydrocarbons.

Pierre MADL
Div. of Material Sciences
Dep. Physics & Biophysics
University of Salzburg
Hellbrunnerstr. 34
A-5020 Salzburg
pierre.madl@sbg.ac.at
http://biophysics.sbg.ac.at/talk/trott-2012.pdf

v.2019.01

Source: http://www.esrl.noaa.gov/csd/groups/csd2/instruments/pcvi/
Part IV

Equipment
Methodology (1/10)

Selecting a proper sampling tool:
There is no technique that covers all
- Selection of size range
  suggests proper technique

No one technique is capable of measuring the size distribution of atmospheric aerosols from the smallest to the largest diameters of interest, a range covering approximately five orders of magnitude. However, a combination of methods can be used to provide information over this range.

Image: Summary of size ranges covered by various analytical techniques for atmospheric aerosols. TEM, transmission electron microscopy; SEM, scanning electron microscope; LBPI, Low Pressure Berner Impacto; ELPI, Electrical Low Pressure Impactor; AMS, Aerosol Mass Spectrometer.

Determining Particle Size, Number, Mass:

Aerosol sampling utilizes:
- **electrical mobility** to determine the particle diameter (DMA)
- **Light scattering** to determine the particle concentration (CPC)
- **Inertia** to determine density, mass (LPBI / ELPI)

Source: Willeke, 1993

- DMA: in order to detect particle size the DMA utilizes electrical mobility;
- CPC: in order to determine particle number concentration the CPC utilizes optical means;
- Impactor: to determine particle mass based on its aerodynamic diameter;

**Gravimetric:**

High-Volume Sampler (HVS)

- filter membrane;
- pore size approx. 300 nm;
- tends to clog if not replaced.
- flow rate adjustable from 350-1400 L/min.
- gravimetric measuring requires filter conditioning in incubator (prior and after measurement).

Finlayson & Pitts, 2000

---

**High Volume Sampler** (HVS): Fibrous mat type filters include the frequently used paper (cellulose) fiber filter, for example, the Whatman paper filter, and glass-fiber filters. A common fibrous mat filter used for sample collection and air cleaning is known as the HEPA filter (high efficiency particulate air filter) and is made of a combination of cellulose and mineral fibers. A widely used type of fibrous mat filter is the high-volume filter, commonly referred to as HVS. A modification of the HVS filter to increase the total air flow allows the collection of sufficient particulate matter in relatively short time periods (e.g., 2 h) to carry out chemical analysis; this is important for studies of the diurnal variation of various chemical components of the aerosol as well as for minimizing sampling artifacts.

Image: Schematic of High-Volume particulate sampler.

Inertia:

Andersen Cascade Impactor (ACI)

- Bio-Aerosol Sampling;
- with 1 to 8 multi-orifice stages
- cut-off points between 10 and 0.4µm
- when operated at 47.2·E⁻³ m³/s (28.3 L/min).
- inter-comparison w/ models difficult (flows & orifice parameters vary)

Andersen Cascade Impactor (ACI): It is an eight stage cascade impactor fitted with nutrient medium-filled dishes that allows sampling of bioaerosols. In general cascade samplers can be divided into three components:

1. The inlet sampling efficiency is a function of the sampler inlet's ability to extract particles from the ambient air environment; it usually depends on the size, shape, and aerodynamic behavior of the particles being sampled.

2. The removal efficiency is determined by the sampler's ability to remove the particles from the air stream of the sampling inlet and deposit them into or onto the collection medium.

3. The biological aspect of sampling efficiency depends on the sampling and removal of the biological particles without altering their viability or biological activity and on the conditions for the organisms to form colonies or to be otherwise detected as biological particles.

The physical (inlet sampling and removal) and the biological factors must be separated in order to quantify their effects on the overall sampling performance. The results of reported field comparison studies are not easily comparable to each other, partly because the samplers, sampling times, and sampled volumes varied within and between studies and partly due to the different operational principles and parameters of each of the samplers. For minimal bias over a broad particle size range, aspiration into the inlet should occur under isokinetic conditions. Long sampling lines after the inlet may cause significant wall losses of large particles. Dependence of the inlet efficiency on the particle size as well as on wind and sampling conditions can cause significant over- or underestimation of the concentration.

Image: Schematics of Andersen's six-stage cascade impactor.

Methodology (5/10)

Inertia:
Low Pressure Berner Impactor (LPBI)

- 10 different nozzle stages connected in series determine particle diameter between 25 nm – 11.4 \( \mu \text{m} \) @ 54 L/min.

In a stage of the Berner impactor model 2510.015, a set of jet orifices is drilled symmetrically in the periphery of the circle. With the exception of stage 1, which has orifices in two circles, the jet holes form one circle. The stages are numbered so that the first stage has the smallest cutoff diameter. The diameters of the jet holes were measured using an optical microscope equipped with a calibrated sizing grid inside the eyepiece. The resolution of the sizing method was estimated to be about 1 %. The orifices were cylindrical and had sharp, rectangular edges. The impactor had its original configuration, and was equipped with the critical orifice. Stage pressures were measured using separate rings with pressure taps between stages. Four inlet pressures (101.3, 98.8, 89.9, and 79.5 kPa) were used. The pressures 101.3, 89.9, and 79.5 kPa correspond to the standard U.S. atmosphere at the height of 0.0, 1.0, and 2.0 km from sea level, respectively. The inlet volume flow rate was measured by a dry gas meter, which was calibrated against a venturi meter with an accuracy of \( \pm 1 \% \). The absolute pressure for stages 1-5 was measured using an absolute pressure gauge (Druck model DPI 261-PDCR 910, accuracy according to specifications \( \pm 0.05 \text{ kPa} \)). The pressures for stages 6-11 were measured by a micromanometer (Alnor MP6KMD).

Image R: Experimental setup for measurements of operating stage pressures and mass flow rate of the Berner low pressure impactor.[1]
Image C: Principle of operation of cascade impactor.[2]

ELPI™ (Electrical Low Pressure Impactor) is an instrument to measure airborne particle size distribution and concentration in real-time. It operates in the size range of 7 nm – 10 µm, and can be applied to various different types of measurements where the requirements for the instrument include wide particle size range and fast response time. Because of its rapid response, the ELPI™ is an ideal measurement instrument for the analysis of unstable concentrations and size distributions, or the evolution of size distributions. Typical applications for the ELPI™ include combustion aerosol and engine exhaust studies, pharmaceutical inhaler development, air quality measurements and general aerosol research. In ELPI™ the well-known impactor technology is combined with particle charging and electrical detection. The result is a robust instrument to measure particle size distribution in a wide size and concentration range, accurately and in real-time. The use of impactor technology also enables post-measurement chemical analysis of size classified particles. The ELPI™ can also be used to measure particle charge distribution in real-time, and make gravimetric impactor measurements.

During the measurement, the ELPI™ instrument is completely controlled and data saved with easy-to-use ELPIVI software. Besides controlling the instrument operations, the ELPIVI enables monitoring of total concentration and particle size distribution of the sample in real-time. The software also enables operating of several ELPI™ units with one piece of software and sending the data or using the instrument over a network connection.

Source: https://www.dekati.com/products/Discontinued%20Products/Classic%20ELPI%C2%AE
Optical:
Optical Particle Counter (OPC)
- Elastic Light Scattering enables detection range b/w: 250 nm - 40 \( \mu \)m @ 0.3 L/min.
  (discrete: 1·10^3 cm\(^{-3}\) or continuous 10·10^3 - 10·10^6 cm\(^{-3}\))

Szymanski, 2009


Source: Madl, 2003
Szymanski, 2009: Aerosol Summer School University of Vienna.
The BROAD Life Phone is a cell phone with a built-in OPC. This hand-held device enables particle measurements in three different size classes. Particle number concentrations are given in [particles/L].

The table on the right shows sample measurements (mean values of at least 3 individual measurements at a given loco) as performed on the 30th of April 2012 at the following locations:

i) ChangSha – downtown measurement in the provincial capital of HuNan province (China);

i) BeiJing – measurements made in front of BeiJing-West railway station and outside Terminal 2 of BeiJing airport;

i) Plane – cabin air in economy class as measured while flying over Sibiria on board an LH723 flight from BeiJing to Munich;

i) Bavaria – measurements outside Munich airport, Munich railway-station (Munich-Est), and Salzburg downtown (AUT);

i) Lab-BLP – Measurement using the Broad Life Phone with filtered lab-air at the University of Salzburg (two days later);

i) Lab-OPC – Measurement using a Grimm.1.109 as a reference unit with the same filtered lab-air (two days later);

Comment: there is slight deviations between the Broad and Grimm instrument, which seem to be related to calibration issues;

Source: Clean Air - BROAD Group / BROAD Town, ChangSha, HuNan, CHN; www.broad.com
In this study, we comprehensively evaluated the first, and the only available, mobile phone-BROAD Life equipped with air pollution sensors (PM$_{2.5}$ and VOC), to answer the question whether this technology is a viable option in the quest of reducing the burden of disease to air pollution. We tested its performance, applicability and suitability for the purpose by subjecting it to varied concentrations of different types of aerosol particles (cigarette smoke, petrol exhaust and concrete dust) and formaldehyde under controlled laboratory conditions, as well as to ambient particles during field measurements. Six reference instruments were used in the study: AEROTRAK Optical Particle Counter (OPC model number 9306), DustTrak, Aerodynamic Particle Counter (APS), Scanning Mobility Particle Sizer (SMPS), Tapered Element Oscillating Microbalance (TEOM) and Formaldehyde Analyser. Overall, we found that the phone's response was linear at higher particle number concentrations in the chamber, above 5 and 10 µgm$^{-3}$, for combustion and concrete dust particles, respectively, and for higher formaldehyde concentrations, making it potentially suitable for applications in polluted environments. At lower ambient concentrations of particles around 10 and 20 µgm$^{-3}$ for PM$_{2.5}$ and PM$_{10}$, respectively, the phone's response was below its noise level, suggesting that it is not suitable for ambient monitoring under relatively clean urban conditions.

Fig 3. Time series of particles number concentrations measured during the chamber experiments. a) Cigarette smoke particles in the size fraction: 2.5 & 10 µm; Concrete dust particles in the size fraction: 2.5 & 10 µm.

Optical: Broad Life-Phone

- Is a cell phone with integrated OPC
- Classification of 3 size channels:
  - 10 µm
  - 2.5µm
  - 0.3µm
- Concentration readout in [particles /L]
- Sampling cycle / measurement: 30 secs

In this study, we comprehensively evaluated the first, and the only available, mobile phone-BROAD Life equipped with air pollution sensors (PM$_{2.5}$ and VOC), to answer the question whether this technology is a viable option in the quest of reducing the burden of disease to air pollution. We tested its performance, to detect formaldehyde under controlled laboratory conditions, The phones underestimate the formaldehyde concentrations and have low resolution in response to formaldehyde, indicated by the discrete horizontal steps of the values in the graph. However, there is a good correlation between the phones and the formaldehyde analyser, with R$^2$ of 0.98 and 0.97 for M1 and M2, respectively. The table presents a summary of the results obtained from testing the phones' response to different VOC sources. As can be seen from Table 2, the response varied, dependently on the VOC source, but there was no response to dish washing liquid and laundry detergent. The measurement range of the phone for VOC is 0±3. The response was categorized according to the following scale: strong (readings >2.5 ppm), medium (2.5 ppm < readings >0.1 ppm), weak (readings <0.1 ppm) and none (no response).

Table 2. Response of the phones to the VOC sources. Strong (readings > 2.5 ppm), medium (2.5 ppm < readings > 0.1 ppm), weak (readings < 0.1 ppm) and none (no response).

The BROAD Life Phone is a cell phone with a built-in OPC. This hand-held device enables particle measurements in three different size classes. Particle number concentrations are given in [particles/L], CO2-concentration [ppm], Volatile Organic Compounds [ppm], and electromagnetic radiation [μW].

The table on the right shows sample measurements (performed with the “Broad air monitor” device during the month of Feb, 2017) showing the three different size classes 0.3 / 2.5 / 10 μm; the total particle concentration over these size classes is nominated as “TSP” besides that of the pCO2-concentration.

ChangSha data (30th Jan til 23rd of Feb 2017);
Salzburg Data (23rd Feb – 28th Feb 2017);
The size class marked with an asterisks (*) suggests estimated values for the particle range PN 0.01 to 0.3 μm and are beased on interpolations of the aerosol inventory measured in the NanJing area.[2]

Image: composite graph using APS, SMPS, WPS-data [1]

Source: Clean Air - BROAD Group / BROAD Town, ChangSha, HuNan, CHN; www.broad.com
**Methodology (8/10)**

**Composite index (AQI) of:**
- PM$_{2.5}$ 0.3-2.5 μm
- CO$_2$ 0.4-10 ppt
- Temperature -10 to +40 °C
- Humidity 0-100 %
- not included in node (CO, O$_3$, SO$_2$, NO$_2$):

Aerosol Climate Health ModelTools

Web-based:
AirVisual Node Detector

---

Aerosol | Climate | Health | Tools | Model

**Web-based:** AirVisual Node Detector

Composite index (AQI) of:
- PM$_{2.5}$ 0.3-2.5 μm
- CO$_2$ 0.4-10 ppt
- Temperature -10 to +40 °C
- Humidity 0-100 %
- not included in node (CO, O$_3$, SO$_2$, NO$_2$):

**Methodology (8/10)**

Air Quality Index (AQI) Values | Levels of Concern | Health | Colors
---|---|---|---
0 to 50 | Good | No health implications. |
51 to 100 | Moderate | Few hypersensitive individuals should reduce outdoor exercise. |
101 to 150 | Unhealthy for Sensitive Groups | Slight irritations may occur, individuals with breathing or heart problems should reduce outdoor exercise. |
151 to 200 | Unhealthy | May have harmful impacts on patients and members of sensitive groups (children, aged or weak people), and also cause the general public unpleasant feelings. |
201 to 300 | Very Unhealthy | Healthy people will be noticeably affected. People with breathing or heart problems will experience reduced endurance in activities. These individuals and elders should remain indoors and restrict activities. |
301 to 500 | Hazardous | Healthy people will experience reduced endurance in activities. There may be strong irritations and symptoms and may trigger other illnesses. Elders and the sick should remain indoors and avoid exercise. Healthy individuals should avoid outdoor activities. |

---

Aerosol Climate Health ModelTools

Aerosol Climate Health ModelTools

---

AQI, or Air Quality Index, is a system for reporting the severity of air quality levels in relatable terms to the public. The index ranges from 0 to 500, where higher index values indicate higher levels of air pollution and higher potential for adverse health effects. An AQI value of 0-50, for example, represents good air quality, while any value larger than 300 is considered to be hazardous. AQI is computed in different ways around the world. China and America, however, have the two most widely used indexes. Both are similar in that they include the same six criteria pollutants (ground-level ozone, PM$_{2.5}$, PM$_{10}$, carbon monoxide, sulphur dioxide and nitrogen dioxide) to generate an overall AQI.

**AQI:** The Chinese AQI takes the highest of all 6 pollutant index values and declares that number the overall AQI. The American index, on the other hand, is calculated by weighing the six criteria pollutants in a fairly complex formula. Since the American method typically yields a higher AQI than Chinese method, it is thought to be more strenuous. It is for this reason, among others, that the American index has become the general world standard. Regardless of which index you use, both yield index values relatively close to one another so the advisory warnings do tend to be fairly consistent.

Source: https://airvisual.com/node
https://airvisual.com/air-quality/aqi
Methodology (9a/10)

Optical:
Scanning Mobility Particle Sizer (SMPS)

Composed of two subunits:

• Dynamic Mobility Analyzer determines Particle Diameter

• Condensation Particle Counter determines Numerical Concentration


Source: Madl, 2003
Scanning Mobility Particle Sizer (SMPS)

- Dynamic Mobility Analyzer determines particle diameter b/w 5.5-350 nm or 11.5-1086 nm @ 0.3L/min.
- Condensation Particle Counter determines numerical concentr. (discrete: 1-10^4 cm^-3 or continuous 10^5 - 10^6 cm^-3)

Grimm, 2003


Source: Madl, 2003
Impactor:
To exclude all particles exceeding the sub-micrometer range – which can house multiple charges (unsuitable for size determination within the DMA), an impactor is mounted onto the aerosol inlet of the electrostatic classifier. All inertial impactors operate on the same principle. As shown in Fig. II.9-2, an aerosol is passed through a nozzle. According to Bernoulli’s principle[1], the constriction in the orifice results in a faster moving aerosol jet.

The exiting jet is directed against the flat impaction plate. This plate deflects the flow to form an abrupt 90° bend in the streamlines.
The orifice of the nozzle has such a diameter that particles with sufficient inertia (i.e. larger than 1 μm) are unable to follow the streamlines and impact on the slightly greased plate (usually silicon grease is used for that purpose). Smaller particles avoid hitting the plate and remain airborne.

TSI, 2001;
**Diffusionsaufladung** (Bipolar): Befinden sich in einem Aerosol noch zusätzlich Ionen, so kommt es durch diffusive Prozesse (Brown’sche Molekular-bewegung) der Ionen und Partikel häufig zu Kollisionen der Ionen mit den Partikeln. Dabei findet ein Ladungsübertrag statt, der neutrale Partikel auflädt bzw. geladene Partikel neutralisiert.

**Ionen** (Entstehung, Eigenschaften): Durch die Träergasmoleküle ionisierende Prozesse (Strahlung, thermische Ionisation) werden stets kurzlebige primäre Ionen (Elektronen, \(N_2^+, O_2^+\) etc.) erzeugt, die durch sofortige Anlagerung an neutrale (zumeist polare Moleküle) zu zeitlich relativ stabilen Ionenclustern anwachsen.

Scan: The cumulative charge concentration vs. electrical mobility shows the concentration of +1, to +6 charges distributed over the size channels for a simulated log-normal aerosol distribution. The assumed total number concentration is \(10^3\) particles/cm³.

**Neutralizer**: The dry polydisperse aerosol entering the EC, is passed over an \(^{241}\text{Am}\) bipolar discharger, (neutralizer), that exposes the aerosol particles to high concentrations of bipolar ions which alters the charge distribution to Boltzmann’s equilibrium. In that process, the particles and ions undergo frequent collisions due to the random thermal motion of the ions. The particles – within milliseconds -- reach a state of equilibrium, in which the particles carry a bipolar charge distribution (in the free atmosphere, cosmic radiation would take as much as 30 mins to achieve that)\[1\].

Measuring Nano-Particles:
- Impactor stage @ inlet of DMA
- Neutralizer @ inlet of DMA

\(^{241}\)Am: \(\alpha\)-emitter, 3.7 MBq \hspace{1cm} (241Am: a-emitter, 3.7 MBq)

<table>
<thead>
<tr>
<th>(d_e ) [(\mu m)]</th>
<th>(n)</th>
<th>-4</th>
<th>-3</th>
<th>-2</th>
<th>-1</th>
<th>0</th>
<th>+1</th>
<th>+2</th>
<th>+3</th>
<th>+4</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.01</td>
<td></td>
<td></td>
<td></td>
<td>0.34</td>
<td>99.52</td>
<td>0.34</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.02</td>
<td></td>
<td></td>
<td></td>
<td>5.23</td>
<td>89.53</td>
<td>5.23</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.04</td>
<td></td>
<td>0.23</td>
<td></td>
<td>16.22</td>
<td>67.10</td>
<td>16.22</td>
<td>0.23</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.06</td>
<td>0.01</td>
<td>1.25</td>
<td></td>
<td>21.36</td>
<td>54.88</td>
<td>21.36</td>
<td>1.25</td>
<td>0.01</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.08</td>
<td>0.08</td>
<td>2.780</td>
<td>23.37</td>
<td>47.53</td>
<td>23.37</td>
<td>2.780</td>
<td>0.08</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.10</td>
<td>0.26</td>
<td>4.39</td>
<td>24.09</td>
<td>42.52</td>
<td>24.09</td>
<td>4.39</td>
<td>0.26</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.20</td>
<td>0.32</td>
<td>9.66</td>
<td>22.63</td>
<td>36.06</td>
<td>22.63</td>
<td>9.66</td>
<td>2.33</td>
<td>0.32</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.40</td>
<td>2.19</td>
<td>5.92</td>
<td>12.65</td>
<td>18.64</td>
<td>21.26</td>
<td>18.64</td>
<td>12.05</td>
<td>5.92</td>
<td>2.19</td>
<td></td>
</tr>
<tr>
<td>0.60</td>
<td>3.82</td>
<td>7.41</td>
<td>11.89</td>
<td>15.79</td>
<td>17.36</td>
<td>15.79</td>
<td>11.89</td>
<td>7.41</td>
<td>3.82</td>
<td></td>
</tr>
<tr>
<td>0.80</td>
<td>4.83</td>
<td>11.32</td>
<td>14.00</td>
<td>15.03</td>
<td>14.00</td>
<td>11.32</td>
<td>7.94</td>
<td>4.83</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.00</td>
<td>5.42</td>
<td>8.06</td>
<td>10.71</td>
<td>12.70</td>
<td>13.45</td>
<td>12.70</td>
<td>10.71</td>
<td>8.06</td>
<td>5.42</td>
<td></td>
</tr>
</tbody>
</table>

**Charge Distribution**: The Boltzmann charge distribution assumes that the distribution is symmetrical around zero; that is, the fraction of particles with \(n\) positive charges equals the fraction with \(n\)-negative charges. Thus, when particles are exposed to a gaseous medium containing bipolar ions, the particles and ions will undergo frequent collisions due to random thermal (Brownian) motion. Thus, in time, an equilibrium state is attained in which the particles carry a bipolar charge distribution[1].

Most of the particles with diameters <0.1 mm carry no more than one unit of charge. The Boltzmann distribution is integrated into the SMPS software, the program considers up to six electrical charges per particle, making the detection of particles in-between the size range of 10 to 800 nm quite accurate.

When dealing with particles >1\(\mu\)m not only contribute to a decreased instrument accuracy (>5%), but also in lower number of particles carrying a single charge (here multiple charges/particle are common), thus resulting in reduced detection efficiency per size class (bin).

Source: [1] For details regarding the ratio of particles carrying 1, 2, 3 (\(np\)) elementary charge units to uncharged particles, refer to the instruction manual of the 3071A Electrostatic Classifier from TSI, p.8-2.
Measuring Nano-Particles:

- Impactor stage @ inlet of DMA
- Neutralizer @ inlet of DMA
- Monodisperse exit slit w/n DMA

**Dynamic Mobility Analyzer:** By grounding the outer cylinder and applying a negative voltage to the centre rod the particles carrying a positive charge can be separated from the pool of particles. For a given voltage, charged particles with mobilities greater than a certain amount will migrate to the oppositely charged cylinders as the aerosol gas stream pushes them through. Uncharged particles pass through unaffected.

Source: TSI, 2002
Madl, 2006;
**SMPS (3b/4)**

Measuring Nano-Particles:
- Impactor stage @ inlet of DMA
- Neutralizer @ inlet of DMA
- Monodisperse exit slit w/n DMA

Generating a monodisperse particle distribution

**Principle:** Differentiation due to electrostatic potential b/w electrodes

![Graph showing voltage vs. particle size](image)

*e.g.: ~200V\(_{DC}\) for 100 nm*

---


Dynamic Mobility Analyzer: The laminar flowing aerosol is fed into the classifier. A sheath of particle free air surrounds the central rod. At the beginning of a scan, the inner cylinder is maintained at the same potential as the outer cylinder; i.e. grounded. Once the scanning process is started, the center rod voltage gradually decreases in voltage (low voltage for tiny particles, higher voltage for larger particles).

Source: Grimm, 2004;
SMPS (4a/4)

Measuring Nano-Particles:
• Impactor stage @ inlet of DMA
• Neutralizer @ inlet of DMA
• Monodisperse exit slit w/n DMA
• CPC

Challenge: particles are too small –
i.e.: below wavelength of light;

Principle: Saturator:
Butyl-Alcohol evaporation
Condenser: Nucleous condensation – up to 10µm
Detection: Counting through light scattering


CPC: A CPC uses with monochromatic light of a single frequency (usually 780nm laser) by focusing on the passing train of particles to detect them. Since such a wavelength falls short to detect particles in the smaller size range (<700nm), the sized aerosols from the DMA must undergo condensation to increase in size. CPCs saturate an aerosol by alcohol vapour and then to cool it in a supersaturated environment (condenser) to achieve rapid growth to micrometer particles under steady flow conditions. The CPC consists of a saturator, condenser, and particle detector. As the monodisperse, unipolar and positively charged particle train enters the CPC, it is saturated with n-Butyl alcohol vapour as it passes over a heated pool of alcohol. The residence time is such that the aerosol will be saturated with the working fluid at a set temperature of 35°C (308 K). Then, the vapour-saturated aerosol flows into the 10°C (283 K) cold condenser, where it is cooled by thermal diffusion. Here the cooled alcohol rapidly condenses onto the particle resulting in net diameter gain of the particles.

Source: Grimm, 2004;
Measuring Nano-Particles:
• Impactor stage @ inlet of DMA
• Neutralizer @ inlet of DMA
• Monodisperse exit slit w/n DMA
• CPC

essential units within the counter:

CPC (Condensation Particle Counter):

Source: TSI, 2002;
Measuring Nano-Particles:
- Impactor stage @ inlet of DMA
- Neutralizer @ inlet of DMA
- Monodisperse exit slit w/ n DMA
- CPC

essential units within the counter:

.... for details see SMPS checklist

For further insight on how to service an SMPS, please see:
http://biophysics.sbg.ac.at/protocol/checklist.pdf
http://biophysics.sbg.ac.at/protocol/checklist2.pdf
Measuring Nano-Particles:

Using the SMPS w/ and w/o the neutralization source generates huge deviations only within the sub-20nm-range;

i) w/o $^{241}$Am: aerosol inventory as is (pred..neg. charged ions);

i) w/ $^{241}$Am: neutralized aerosol

Source: Kolarz et al., 2012

Operating the SMPS w/o radiation source: since we operated our setup without the $^{241}$Am neutralizer, it implies that the particles with multiple charges detected by the SMPS shift from the original size bin to one that corresponds to a net smaller size bin (due to the multiple charge loading, such a particle behaves like a smaller one); thus, the spectrum obtained with the SMPS in the larger size range (>50nm) is smaller in amplitude than it really is. The graph depicts the sampled inventory belonging to a given site that was probed with (blue plot) and without (red plot) the $^{241}$Am radiation source (the neutralizer causes the aerosol to be discharged according to the Boltzmann distribution pattern). In both scans the 100nm fraction is well represented, whereas the 10nm range is completely stripped off the spectra when the $^{241}$Am-source was attached to the DMA. This indicates that in comparison, the size distribution is present in principle, yet the actual number concentration of the raw aerosol (not using the $^{241}$Am radiation source) can not accurately be determined with the setup we used.

Since we assumed that multiple charges on water aerosols contribute in the distortion of the spectra towards the smaller size bins – a fact that can hardly be deduced from the above scans – the evidence presented so far shall be enough to say that multiple charges on few larger particles do not heavily interfere with the bulk of smaller particles.

Measuring Nano-Particles:
Gerdien condenser
Using Faraday Cup
Electrometer (FCE)

Charge (2/3)

During a three-year field campaign of measuring waterfall generated ions, we monitored five different waterfalls in the Austrian Alps. Most measurements were performed at the Krimml waterfall (Salzburg), which is the biggest and most visited one in Europe and 5 the Gartl waterfall (Moelltal, Carinthia). Smallest ion sizes (0.9–2 nm) were measured with a cylindrical air ion detector (CDI-06) while ion sizes from 5.5 to 350 nm were measured using a modified Grimm SMPS aerosol spectrometer. Measurements showed high negative ion gradients nearby waterfalls whereas positive ions showed only a moderate increase. The most abundant sizes of nano-sized and sub-micrometer ions measured were at 2 nm and of the larger and heavier ones at 120 nm.

Image left: The aspirated Gerdien condenser (CDI-06) is a widely utilized instrument for the air-ion concentrations and mobility measurements. It is a fully automated portable instrument with ability to alternatively measure concentrations of positive and negative airions, temperature (T), pressure (P) and relative humidity (RH).

Image right: **Negative** air ion concentrations vs. size for different distance measuring points at Krimml WF. Shaded area indicates interpolated values (cubic B-spline) between CDI-06 (0.9–2.0 nm) and SMPS (5.5–350 nm, without $^{241}$Am-Source) measurements. The 547 m data series (magenta curve) represents the reference site where no WF generated ions were expected to occur.


Precise measurements of air ions in indoor areas, function rooms, production areas and vehicles are becoming ever more vital. Due to their low electrical charge, air ions demand high technical requirements of the ionometer, which is the measurement device used to measure the ion concentration. The ionometer IM806V2 – the successor of the IM806 – features two measurement channels for simultaneous measurement of air ions with positive and negative electrical charges.

The measuring system consists of two outer electrode tubes (1 & 2), each of which holds a centric and electrically insulated smaller electrode. A DC potential is applied between the outer and inner electrodes, thus generating a DC electric field between the electrodes. The fan (4) continuously draws air at a defined flow rate through both of the electrode tubes. The DC electric field exerts a force in the vicinity of the electrodes on the ions in the streaming airflow (Coulomb’s law) and deflects them to the inner electrodes. Since the polarities of the applied voltage differ in both electrodes, one electrode accelerates the positively charged ions and the other electrode the negatively charged ions to the inner electrode. The air flow velocity, the level of the deflection voltage and the geometry of the electrodes are dimensioned such that ions of a defined ion mobility reach the inner electrode. Air ions of lower ion mobility (medium and large ions) only partially reach the inner electrode.

At very high ohmic resistances (R) (up to \(10^{11}\) ohm), the charge current flowing during the charge neutralisation generates a measurable drop in voltage, which is boosted using suitable measuring amplifiers (3) to a measurable signal proportional to the air ion concentration and then digitalised in the pre-amplifier (6). The entire sequence of operations is controlled using a microcontroller (5) which also handles the display, the storage logic, the analog outputs (7), the USB interface, the network interface and the climate sensors. The IM806V2 has an integrated barometric pressure sensor.

https://www.holbach.biz/upload/manual_im806_1_4.pdf
f-shift PM-detector (1/2)

Measuring Nano-Particles:
Quartz Crystal Microbalance:

- miniature, light-weight sensor
- fast response time (high $f_{res}$ 6MHz)

![Graph showing frequency shift vs. mass change](source: novaetech)

Sauerbrey was the first to recognize the potential usefulness of the Quartz Crystal Microbalance (QCM) technology and demonstrate the extremely sensitive nature of these piezoelectric devices towards mass changes at the surface of QCM electrodes. The results of his work are embodied in the Sauerbrey equation, which relates the mass change per unit area at the QCM electrode surface to the observed change in oscillation frequency of the crystal: $\Delta f = - Cf \cdot \Delta m$

The Sauerbrey equation relies on a linear sensitivity factor, $Cf$, which is a fundamental property of the QCM crystal. Thus, in theory, the QCM mass sensor does not require calibration. However, it must be kept in mind, that the Sauerbrey equation is only strictly applicable to uniform, rigid, thin-film deposits. Vacuum and gas phase thin-film depositions which fail to fulfill any of these conditions actually exhibit more complicated frequency-mass correlations and often require some calibration to yield accurate results.


http://mwrf.com/active-components/manage-quartz-crystals-under-high-vibration
http://www.novaetech.it/en/sensors-devices/#/prettyPhoto
Measuring Nano-Particles: Tapered Element Oscillating Microbalance (TEOM):

- PM$_{2.5}$ & PM$_{10}$
- continuous operation
- no filter changes required (as frequently as high-volume air samplers do).
- being real-times, it reveals diurnal fluctuations
- enables source appointment of particle emissions.

Source: Ionel & Popescu, 2010

Tapered element oscillating microbalance (TEOM) is a technique used to measure concentrations of air particles. It consists of an instrument fitted with a size-selective inlet to sample one of the following particle size ranges:

- total suspended particulate (TSP)
- particles less than 10 micrometres in diameter (PM$_{10}$)
- particles less than 2.5 micrometres in diameter (PM$_{2.5}$).

A pump draws a sample into the instrument at 16.7 litres per minute (L/min) through an inlet designed to allow only particles of the required size range to pass through. This air stream is then split so that 3L/min of sample is directed to the tapered element while the remainder is sent to exhaust. The tapered element consists of a filter cartridge mounted on the tip of a hollow glass tube. The base of the tube cannot move, but the tip is free to vibrate at its natural frequency (in a similar way to a tuning fork). Any additional weight from particles that collect on the filter changes the frequency at which the tube oscillates. The electronic circuitry senses this change and calculates the particle mass rate from the magnitude of the frequency change. The instrument then returns the vibrating glass tube to its natural frequency ready for the next measurement. The instrument maintains a constant temperature and flow rate, and electronically smooths the readings to reduce noise. Dividing the mass rate by the flow rate provides a continuous output of the particle mass concentration.

Available from: http://www.intechopen.com/books/air-quality/methods-for-online-monitoring-of-air-pollution-concentration
AOD uses a sun photometer which is a type of photometer conceived in such a way that it points at the sun. Recent sun photometers are automated instruments incorporating a sun-tracking unit, an appropriate optical system, a spectrally filtering device, a photodetector, and a data acquisition system. The measured quantity is called direct-sun radiance. When a sun-photometer is placed somewhere within the earth's atmosphere, the measured radiance is not equal to the radiance emitted by the sun (i.e. the solar extraterrestrial radiance), because the solar flux is reduced by atmospheric absorption and scattering. Therefore, the measured radiant flux is due to a combination of what is emitted by the sun and the effect of the atmosphere; the link between these quantities is given by Beer's law. The atmospheric effect can be removed with Langley extrapolation; this method therefore allows measuring the solar extraterrestrial radiance with ground-based measurements. Once the extraterrestrial radiance is known, one can use the sun photometer for studying the atmosphere, and in particular for determining the atmospheric optical depth. Also, if the signal at two or more suitably selected spectral intervals is measured, one can use the information derived for calculating the vertically integrated concentration of selected atmospheric gases, such as water vapour, ozone, etc.

The Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observation (CALIPSO) satellite provides new insight into the role that clouds and atmospheric aerosols (airborne particles) play in regulating Earth's weather, climate, and air quality. CALIPSO combines an active lidar instrument with passive infrared and visible imagers to probe the vertical structure and properties of thin clouds and aerosols over the globe. CALIPSO was launched on April 28, 2006 with the cloud profiling radar system on the CloudSat satellite. CALIPSO and CloudSat are highly complementary and together provide new, never-before-seen 3-D perspectives of how clouds and aerosols form, evolve, and affect weather and climate. CALIPSO and CloudSat fly in formation with three other satellites in the A-train constellation to enable an even greater understanding of our climate system from the broad array of sensors on these other spacecraft.

Source: https://en.wikipedia.org/wiki/AERONET.
http://www-calipso.larc.nasa.gov/
Aerosol optical and radiative properties have, for the first time, been retrieved from ground-based measurements in Karachi, Pakistan. Ground-based aerosol measurements were obtained using a GRIMM Model 1.109 optical particle counter (OPC). The optical and radiative properties of aerosols were retrieved from these measurements using the Aerosol Robotic Network (AERONET) inversion algorithm. The volumetric size distribution obtained from the OPC measurements shows three distinct modes, one fine and two coarse, with a fine mode particle diameter of about 0.29 µm and coarse mode particle diameters of about 7 µm and 22.5 µm. An overlap in between the size range of 0.25 µm to 7 µm has been carried out by using OPC data together with data obtained from AERONET. The obtained OPC-transposed data set (OPCAOD) was compared with those obtained from Moderate Resolution Imaging Spectroradiometer (MODIS) satellite and AERONET Sunphotometer. The analysis revealed a moderate correlation of 0.57 between OPC AOD and MODIS AOD data but only low correlations between OPC AOD and AERONET AOD data (0.21), and between MODIS AOD and AERONET AOD data (0.26). The Single Scattering Albedo (SSA) for the measurement days, calculated at a wavelength of 676 nm, ranged from 0.83 ± 0.01 to 0.90 ± 0.02, showing slight variations in magnitude between the different measurement days. The asymmetry parameter (ASY), a wavelength-dependent quantity, was calculated for the same wavelength yielding values that ranged from 0.59 ± 0.01 to 0.68 ± 0.02. The aerosol radiative forcing (ARF) values measured for the period of observation at the top of the atmosphere, at the earth’s surface, and within the atmosphere ranged from 31.2 Wm⁻² to –28.27 Wm⁻², from –69.76 Wm⁻² to –73.57 Wm⁻², and from 38.56 Wm⁻² to 45.3 Wm⁻², respectively.

Source: https://en.wikipedia.org/wiki/AERONET.
http://aeronet.gsfc.nasa.gov/new_web/operations.html
Lidar (2/2)

Measuring Nano-Particles:
Light Detection and Ranging (LIDAR):

- Polar stratospheric clouds (PSC) occur in polar winter and spring – indicator of ozone depletion.
- Polar mesospheric clouds (PMC) usually occur in polar summer - indication of global climate change
- Increasing PMC brightness or frequency may provide an early indication of longterm climate change in the middle and upper atmosphere

Source: Chu, 2012

LIDAR stands for “Light Detection and Ranging”, commonly known as Laser Radar. Lidar technology has since expanded vastly in capability and lidar systems are used to perform a range of measurements that include profiling clouds, measuring winds, studying aerosols and quantifying various atmospheric components. Atmospheric components can in turn provide useful information including surface pressure (by measuring the absorption of oxygen or nitrogen), greenhouse gas emissions (CO₂ and CH₄), photosynthesis (CO₂), fires (CO) and humidity (H₂O-vapor). Atmospheric lidars can be either ground-based, airborne or satellite depending on the type of measurement. Atmospheric lidar remote sensing works in two ways -

i) by measuring backscatter from the atmosphere, and

i) by measuring the scattered reflection off the ground (when the lidar is airborne) or other hard surface.

Backscatter from the atmosphere directly gives a measure of clouds and aerosols. Other derived measurements from backscatter such as winds or cirrus ice crystals require careful selecting of the wavelength and/or polarization detected. Doppler Lidar and Rayleigh Doppler Lidar are used to measure temperature and/or wind speed along the beam by measuring the frequency of the backscattered light.

Source: superlidar.colorado.edu/Classes/Lidar2012/
PMC-image: Pekka Parviainen
http://www.ung.si/~sstanic/CRA/lidar/otlica/index.html
http://www.abc.net.au/catalyst/stories/2867591.htm
Unmanned Areal Vehicle (UAV) – prototype III:

- Fully digitalized RC-unit
- Digital IR- & VIS camera
- I²C rad. Detectors (γ & X-rays)
- Gas-cell (nephelometer using IR)
- Particle mass (QCM) & number concentration (OPC, 0.3, 2.5, 10 µm)
- Onboard PC (black box) & high-power transceiver unit.
- Total weight: 7200 g
- Avg time airborne: 20min

The herein presented design is part of the BRIDGE Concept Case Advanced Situation Awareness for proactive risk management. It will fill this gap by providing the user inter alia with real-time data on the extent of airborne pollution inventories (aerosols, gases, radiation) and thermographic imaging. One of the core-component is a manually controlled unmanned aerial vehicle (UAV), termed PLUS-copter (Fig.1). As shown in the schematic diagram Fig.2, the system consists of a ground-station, a wireless communication link and the sensor-equipped flying platform. The latter houses 8 electric motors, Global Positioning System (GPS) for stabilized flying mode, two different cameras, i.e. visual (VIS) / infra-red (IR), an onboard-computer and several solid state sensors (T, rH, p, β, γ) as well as an optical particle number counter OPC (PN) for numeric particle detection and a quartz crystal microbalance (QCM) to monitor particle mass (PM). Table 1 summarizes the core specifications.

Image: Schematic block diagram of the UAV: Legend: Tx, Rx transmitter & receiver; M, step motor; M1-8, lifting rotors; P, pumps; VIS & IR: USB-compatible cameras; CPU, central processing unit; USB: universal serial bus; 10&100BT: bidirectional wireless ethernet link; T, rH, p, β, γ, PM, PN: sensors (see above).

Unmanned Aerial Vehicle (UAV) – prototype III:

- Fully digitalized RC-unit
- Digital IR- & VIS camera
- TCP rad. Detectors (γ & X-rays)
- Gas-cell (nephelometer using IR).
- Particle mass (QCM) & number concentration (OPC, 0.3, 2.5, 10 µm)
- Onboard PC (black box) & high-power transceiver unit.
- Total weight: 7200 g
- Avg time airborne: 20 min

Madl et al, 2015

Part I of this series (CRJ 9:3) described the Advance Situation Awareness (ASA) concept, currently developed at the Paris Lodron University of Salzburg (PLUS) within the EU FP7 project Bridging Resources and Agencies in Large-Scale Emergency Management (BRIDGE). The aim of the ASA is to enhance situational awareness at the scene of complex emergencies and disasters. The system consists of three subsystems: A Smart Unmanned Aerial Vehicle (UAV) carrying multiple sensors onboard; Computer-based Expert System (CES), which evaluates incoming information and provides advice based upon this information; and 2D-3D Computer Modelling Module, which provides models of structures damaged by explosions, and estimates the number and type of injuries of blast victims. Part I of the series was dedicated to an overview of the concept and its practical applications. Here, the author looks at the UAVs that are used in more detail, focusing on the UAV.

The environmental changes affecting the world have become a cause for serious concern. One result of this has been the increasingly important role that air pollution monitoring systems have come to play in environmental preservation. Foremost among these is Horiba's AP-360 series of air pollution monitoring systems, which are based on the cross-flow modulation method, developed by HORIBA engineers, and the extension of this principle, the multi-flow method. These systems are capable of stable and simultaneous measurement of carbon monoxide (CO), ozone (O$_3$), methane (CH$_4$), non-methane hydrocarbon (NMHC), total hydrocarbons (THC), nitrogen oxide (NO), nitrogen dioxide (NO$_2$), and nitrogen oxides (NO$_X$) in the air. This paper describes the principles and applications of cross-flow modulation.

**APMA-360 Carbon Monoxide Analyzer:** Molecules composed of more than one element, like CO, selectively absorb infrared light at a specific frequency. The APMA-360 CO analyzer uses this property to measure the CO concentration. The APMA-360 consists of a light source, a cell, a detector, an optical filter, and a flow modulator. In conventional NDIR, a rotating partition is used to alternately cut off and modulate the sample cell and reference cell in order to obtain a signal. By contrast, in an infrared analyzer using the cross-flow modulation method, fixed amounts of sample gas and zero gas are alternately introduced into the measurement cell, and an alternating current is produced as a signal as a result of the two gases' different absorption strengths. This method has the advantage of eliminating measurement error (ensuring zero drift) caused by soiling of the optical system in the analyzer, or deterioration of the optical system. The result is stable measurements over long periods.

In the APMA-360, oxidation catalysts remove only the carbon monoxide in the sample gas so that this gas can be used as the zero gas. Therefore, even if there are interfering components present in the sample gas, their influence can be ignored because they are present in the zero gas as well. This allows an accurate signal for only the desired component to be extracted. Figure 2 shows the basic principles of non-dispersive infrared absorption analysis using the cross-flow modulation method.

The environmental changes affecting the world have become a cause for serious concern. One result of this has been the increasingly important role that air pollution monitoring systems have come to play in environmental preservation. Foremost among these is Horiba's AP-360 series of air pollution monitoring systems, which are based on the cross-flow modulation method, developed by HORIBA engineers, and the extension of this principle, the multi-flow method. These systems are capable of stable and simultaneous measurement of carbon monoxide (CO), ozone (O₃), methane (CH₄), non-methane hydrocarbon (NMHC), total hydrocarbons (THC), nitrogen oxide (NO), nitrogen dioxide (NO₂), and nitrogen oxides (NOₓ) in the air. This paper describes the principles and applications of cross-flow modulation.

3.1 APNA-360 Nitrogen Oxide Analyzer: When nitrogen oxide comes into contact with O₃, NO₂ is produced through a chemical reaction. A portion of the generated NO₂ molecules are in an excited state, and these excited molecules generate chemiluminescence (CLD) in the 600 to 3000 nm wavelength region as they return to the ground state. Based on the strength of this light, which is detected by a semiconductor photo-sensor, the concentration of nitrogen oxide can be measured. This concentration of NO₂ and other nitrogen oxides in the air is converted to NO using a preprocessing device (NOₓ converter), and then measured using the CLD method. NO is detected as it reacts through direct exposure to the ozone; after the gas has passed through the converter, NOₓ can be detected as it in turn reacts. Finally, NO₂ is measured by subtracting NO from NOₓ. Figure 4 shows the basic principles of the nitrogen oxide analyzer using the multi-flow modulation method. In this example, the sample gas is designated as A, the sample gas processed by the NOx converter as B, and the zero gas as C. When these gases are introduced into the sample cell in a fixed cycle, signals are generated from the detector in the order A, B, C. In the NO signal processing system, however, the A component is not read, and in the NOₓ system, B is ignored. Like the cross-flow modulation method, the multi-flow modulation method has no zero drift. In addition, this system uses a single detector for the continuous measurement of NO, NO₂, and NOₓ concentrations.

The environmental changes affecting the world have become a cause for serious concern. One result of this has been the increasingly important role that air pollution monitoring systems have come to play in environmental preservation. Foremost among these is Horiba's AP-360 series of air pollution monitoring systems, which are based on the cross-flow modulation method, developed by HORIBA engineers, and the extension of this principle, the multi-flow method. These systems are capable of stable and simultaneous measurement of carbon monoxide (CO), ozone (O₃), methane (CH₄), non-methane hydrocarbon (NMHC), total hydrocarbons (THC), nitrogen oxide (NO), nitrogen dioxide (NO₂), and nitrogen oxides (NOₓ) in the air. This paper describes the principles and applications of cross-flow modulation.

2.2 APOA-360 Ozone Analyzer: Ozone molecules absorb only specific wavelengths of ultraviolet light, much as different molecules respond to different frequencies of infrared light. This property is used by the APOA-360 ozone analyzer, which also applies the cross-flow modulation method described above. Like the APMA-360, the APOA-360 is capable of stable, highly accurate measurements over a long period of time. Figure 3 shows the basic principles for ultraviolet absorption analysis using the cross-flow modulation method.

The environmental changes affecting the world have become a cause for serious concern. One result of this has been the increasingly important role that air pollution monitoring systems have come to play in environmental preservation. Foremost among these is Horiba's AP-360 series of air pollution monitoring systems, which are based on the cross-flow modulation method, developed by HORIBA engineers, and the extension of this principle, the multi-flow method. These systems are capable of stable and simultaneous measurement of carbon monoxide (CO), ozone (O₃), methane (CH₄), non-methane hydrocarbon (NMHC), total hydrocarbons (THC), nitrogen oxide (NO), nitrogen dioxide (N0₂), and nitrogen oxides (NOₓ) in the air. This paper describes the principles and applications of cross-flow modulation.

**UV fluorescence**: The UV fluorescence method operates on the principle that when the SO₂ molecules contained in the sample gas are excited by ultraviolet radiation they emit a characteristic fluorescence in the range of 220-240 nm. This fluorescence is measured and the SO₂ concentration is obtained from changes in the intensity of the fluorescence. The reactive mechanism is

\[
(1) \text{SO}_2 + h\nu_1 \rightarrow \text{SO}_2^* \\
(2) \text{SO}_2^* \rightarrow \text{SO}_2 + h\nu_2 \\
(3) \text{SO}_2^* \rightarrow \text{SO} + (O) \\
(4) \text{SO}_2^* + M \rightarrow \text{SO}_2 + M
\]

Here, (1) shows the excited state of the SO₂ molecules that have absorbed the amount of energy hν₁ by ultraviolet radiation. (2) shows the amount of energy, hν₂ emitted by the excited molecules as they return to the ground state. (3) shows the decomposition by the light emitted from the excited molecules. (4) shows the quenching, i.e., the energy lost by the excited molecules colliding with other molecules. The APSA-360ACE uses an Xe lamp as the light source, and the fluorescent chamber design minimizes scattered light. The optical system has been carefully designed with low background, making it possible to take measurements with a highly stable zero-point. In addition, a reference detector monitors any fluctuation in the intensity of the light source. This allows the unit to calibrate itself automatically for sensitivity, resulting in greater span stability.

The environmental changes affecting the world have become a cause for serious concern. One result of this has been the increasingly important role that air pollution monitoring systems have come to play in environmental preservation. Foremost among these is Horiba's AP-360 series of air pollution monitoring systems, which are based on the cross-flow modulation method, developed by HORIBA engineers, and the extension of this principle, the multi-flow method. These systems are capable of stable and simultaneous measurement of carbon monoxide (CO), ozone (O₃), methane (CH₄), non-methane hydrocarbon (NMHC), total hydrocarbons (THC), nitrogen oxide (NO), nitrogen dioxide (NO₂), and nitrogen oxides (NOₓ) in the air. This paper describes the principles and applications of cross-flow modulation.

3.2 APHA-360 Hydrocarbon Analyzer: The APHA-360 uses selective combustion and flame ionization detection (FID) for measuring the CH₄ and NMHC concentrations in the air. Selective combustion is a technique making use of the varying combustion temperatures for different species of hydrocarbons. Since CH₄ has a higher combustion temperature than other hydrocarbons, heating the combustion catalysts under controlled conditions results in the combustion of all hydrocarbons in the sample gas except for CH₄. FID works differently in that it produces a reaction in all hydrocarbons. As with the APNA-360, the introduction in set cycles to the FID device of the sample gas, the sample gas which has passed through catalytic processing, and the zero gas, enables the stable measurement of CH₄, NMCH, and THC concentrations. Figure 5 shows the basic principles of the hydrocarbon analyzer using the multi-flow modulation method.

Chemistry (6/6)

Measuring Nano-Particles: Aerosol Mass Spectrometer:

- single particle mass determination (50 nm till 1 µm)
- particle mass composition not yet possible to determine
- volatile & semivolatile chemicals
- single particle mass determination
- aerosol need to be routed from environmental conditions to ultra high vacuum.

Finnlayson & Pitts, 2000

Aerosol Mass Spectrometer (AMS): Single-particle size and composition measurements that is applicable to volatile and semivolatile species over the size range from ~0.05 to 1 µm. Particles are sampled through an aerodynamic inlet that provides a narrow beam of particles with near unit efficiency. As the air containing the particle beam expands into the vacuum at the end of the inlet, the particles are accelerated, with smaller particles attaining higher speeds and vice versa. The beam of particles entering the sizing chamber is chopped to provide a time-of-flight measurement of the time for a particle to reach the detector, from which the particle size can be determined. In the third chamber, the particle collides with a heated surface that flash vaporizes volatile and semivolatile components. The vaporized species are ionized by electron impact and a quadrupole mass spectrometer is used to obtain the mass spectrum. The detection process is sufficiently sensitive to be able to detect single particles larger than 50 nm, so that the number of particles can be determined as a function of particle size.

At present, the full mass range cannot be scanned for one particle so that single-particle analysis is currently not possible with this approach; i.e., a complete mass spectrum cannot be obtained for one particle. Nonvolatile species are also not detected, so that important particle components in soil dust and soot cannot be measured. The advantages compared to single particle laser ionization techniques are that some of the important volatile and semivolatile components such as ammonium sulfate and nitrate can be quantified. There is also much less fragmentation of organics.

Image: Schematic diagram of aerosol mass spectrometer for volatile and semivolatile particle sizing and composition measurement.

Radioactive Aerosols

Measuring Nano-Particles: Lucas Cell Scintillator:

- Exhaled air sampled in Tedlar-bag (5 or 10L)
- Definite volume transferred into Lucas Cell (270cm³)
- Measurement of counts

(*) halftime needs to be considered at start of measurement in relation to filling dime of Tedlar-bag

The Pylon Model 110A and 300A Lucas Cells are scintillation cells which allow the Pylon AB-5 Portable Radiation Monitor to measure radon gas and thoron gas. Scintillation cells are sensitive to three radioactive isotopes. These are radon gas (Rn-222), thoron gas (Rn-220), and actinon gas (Rn-219). These gases are decay products of the uranium 238, thorium 232, and uranium 235 radioactive series respectively. This manual primarily considers radon as it is the most commonly encountered of the three gases. Radon gas is described in more detail in Section 1.2. Thoron gas is less prevalent than radon gas and, because it has a short half-life, its presence tends to be more unpredictable than radon. Thoron gas is described in Section 2.9. Actinon, because it has a very short half-life (3 to 9 seconds) and an uncommon parent material, is rarely encountered.

Concentration below 4 pCi/L: at or below EPA guideline; reduction efforts descretionary.

4 to 20 pCi/L EPA recommends action to reduce level to 4 pCi/L within a few years; sooner for levels at upper end of range.

20 to 200 pCi/L: EPA recommends action to reduce level within several months; sooner for levels at upper end of range.

Above 200 pCi/L: EPA recommends action to reduce level within several weeks.

1 [Ci] = 370·E⁹ [Bq]

Image: basic components required to sample exhaust air from human probands.

Conclusion (1v2)
**Conclusion (1v2)**

Nano-Aerosols in a Nut-Shell:

- crucial for our CLIMATE (rain, snow); micro-organisms and plants could not easily spread – are essential for LIFE as we know it;
- Quantity (number) and Quality (chemo-physical property) are important (not mass);
- are INVISIBLE (particle diameter below the wavelength of light, <400nm);
- readily penetrate micrometer structures (diffusion, gravimetric settlement);
- are not STATIC, depending on their hydro-phobic/-philic property are subject to ongoing dynamic interactions with their environment;
- are CARRIERS of adsorbing agents (from therapeutic to toxic substances);
  - with quantitative and qualitative effects on biological tissue (Trojan Horse);
- remain suspended in the troposphere for extended periods of time

there is no such thing as a GOOD or BAD aerosol:

Hence,

only the DOSE makes the poison (*Paracelsus*, 1493-1541)

Danke für Eure Aufmerksamkeit - Thanks for your attention

18-10-04

**Objectives of the study:** Apart from the importance of aerosols in the global climate budget, huge concentrations of anthropogenically generated aerosols, when released into confined airspaces are of particular interest – both from a therapeutic point of view as well when viewed from an exposure related perspective. While it is the aim of the studies presented therein to show the manifold variations of incompletely oxidized combustion aerosols, some studies focus on aerosol generation and applications suitable for various approaches – be it in the medical field or technical approaches such as air purification systems.

Another aspect which this thesis tries to investigate deals with some theoretical investigation and the fate of aerosols once released into the air. Thereby two issues are of interest: one regards emission factors and aerosol behavior under real world conditions and the other regards inhalability of such aerosols. While the former is subject to abiotic alteration, the latter deals with the inhalability of aerosols and the application of models that enable the calculation of deposition efficiencies within the respiratory tract. In this context, it is also tried to use an animal model that should aid industrial applications where part of the experimental work can be simulated by computer-supported modelling rather than sacrificing countless animals during exposure experiments.

The work presented here represents just a modest contribution to the huge issue generally acknowledged as human ingenuity. Thereby it is hoped that the knowledge made publically available will promote a better understanding of the issue and may contribute to tackle the challenges still awaiting humanity.
.... continue with part 5 (Modelling) ....