## Table 1.4 Gaseous and particle air pollutants and their measurement methods

| Observable | Measurement method | References |
|---|---|---|
| *Individual gases (Common gases can also be measured with instruments shown in the "Multiple gases" category below)* | | |
| Carbon monoxide (CO) | Passive:<br>• Chemical reagent impregnated on silica gel, based on colorimetric dosimeter or solid absorber such as Na-Y-zeolite (LZY-S²) using chemisorption or physisorption, followed by TD-GC-FID<br>Continuous:<br>• NDIR detector<br>• Electrochemical sensor | McConnaughey et al. (1985); Lee et al. (1992), Jantunen (1998), Monn (2001), Lodovici et al. (2003), Orr (2003), Abi Esber et al. (2007), Bhoga & Singh (2007) |
| Nitrogen dioxide ($NO_2$) | Passive (methods often applied to NO and $NO_x$):<br>• Often use TEA- or sodium iodide-/sodium hydroxide-impregnated filter; also use passive colorimetric dosimeter with strip of impregnated paper<br>Integrated:<br>• Saltzman impinger or bubblers with colorimetric detection using a mixture of sulfanilic acid, *N*-(1-naphthyl)ethylenediamine dihydrochloride, and acetic acid<br>• Sampling with front filter to remove particles, followed by TEA-impregnated cellulose-fibre filters for IC analysis of nitrite ($NO_2^-$) as $NO_2$<br>Continuous (some absorbents can be used for NO and $NO_x$):<br>• Chemiluminescence (catalytic reduction of $NO_2$ to NO; reaction of NO with $O_3$), including: (1) photolysis: photolytic converter to reduce $NO_2$ to NO, followed by chemiluminescence, and (2) luminol (5-amino-2,3-dihydro-1.4-phthalazinedione): reaction with $NO_2$, followed by chemiluminescence methods<br>• Electrochemical sensor to detect $NO_2$ by an amperometric method<br>• Photoacoustic spectroscopy<br>• Long-path absorption photometer | Saltzman (1954), Clyne et al. (1964), Clough & Thrush (1967), Ridley & Howlett (1974), Palmes et al. (1976), Ohtsuka et al. (1978), Kley & McFarland (1980), Maeda et al. (1980), Kring et al. (1981), Wendel et al. (1983), Atkins et al. (1986), Mulik et al. (1986), Schiff et al. (1986), Chang & Stetter (1990), Kelly et al. (1990), Parrish (1990), Blatter et al. (1992), Ferm & Sjodin (1993), Willems (1993), Spicer et al. (1994), Pisano et al. (1996), Gaffney et al. (1999), Cohen et al. (2000), Demerjian (2010), Cox (2003), Marley et al. (2004), Bhoga & Singh (2007), Dunlea et al. (2007), Mitrayana et al. (2007), Steinbacher et al. (2007), Deshler et al. (2008), EPA (2010), Sluis et al. (2010), Villena et al. (2011) |
| Nitrogen oxide/ nitrogen oxides ($NO/NO_x$) | See: Nitrogen dioxide ($NO_2$) | |
| Sulfur dioxide ($SO_2$) | Passive:<br>• Huey sulfation plate: Petri dish with glass-fibre filter layered with lead peroxide; other absorbents include sodium tetrachloromercurate ($Na_2HgCl_4$), potassium carbonate ($KCO_3$), sodium bicarbonate ($NaHCO_3$) and sodium carbonate ($Na_2CO_3$), sodium hydroxide (NaOH), and TEA<br>• Colorimetric dosimeter with strip of impregnated paper<br>Integrated:<br>• Gas-wash-bottle method using cellulose-fibre filters to remove particles (gas bottle containing an acidified peroxide solution, gas meter, restrictor, and pump), followed by IC analysis of sulfate as $SO_2$ | Orr et al. (1967), Huey (1968), Reiszner & West (1973), Kring et al. (1981), Beghi et al. (1987), Hallberg & Rudling (1989), Mari et al. (1990), Krochmal & Kalina (1997), Ferm & Svanberg (1998), Bogue (2008) |

**Table 1.4 (continued)**

| Observable | Measurement method | References |
|---|---|---|
| Sulfur dioxide ($SO_2$) (cont.) | • Sampling with front filter to remove particles, followed by potassium carbonate ($KCO_3$)-impregnated cellulose-fibre filters for IC analysis of sulfate as $SO_2$<br>Continuous:<br>• UV fluorescence<br>• Electrochemical sensor | |
| Hydrogen sulfide ($H_2S$) | Passive:<br>• Colorimetric dosimeter with strip of impregnated paper<br>Integrated:<br>• Sampling with front filter to remove particles, followed by silver-nitrate-impregnated cellulose-fibre filters for XRF analysis of sulfur as $H_2S$<br>Continuous:<br>• UV fluorescence: catalytic oxidation to $SO_2$ | Kring et al. (1981), McConnaughey et al. (1985) |
| Ammonia ($NH_3$) | Passive:<br>• Impregnated boric acid ($H_3BO_3$), sodium potassium tartrate ($KNaC_4H_4O_6 \cdot 4H_2O$), tartaric acid (2,3-dihydroxybutanedioic acid), sulfuric acid ($H_2SO_4$), ethylene glycol ($C_2H_6O_2$)/hydrochloric acid (HCl), or citric acid ($C_6H_8O_7$); Nessler's reagent (50 g of manganese iodide [$MgI_2$] and 35 g of potassium iodide [KI])<br>Integrated:<br>• Sampling with front filter to remove particles, followed by citric-acid-impregnated cellulose-fibre filters for automated colorimetric analysis of ammonium as $NH_3$<br>Continuous:<br>• Chemiluminescence: conversion to NO | Sigsby et al. (1973), Benedict et al. (1983), Tang et al. (2001) |
| Ozone ($O_3$) | Passive:<br>• Impregnated nitrite ($NO_2^-$) or nitrate ($NO_3^-$), followed by IC analysis; other absorbents include indigo, indigo carmine, or KI<br>• Treated strips that react with $O_3$ and comparison with colour scale<br>• KI-impregnated filter<br>Integrated:<br>• Sampling with front filter to remove particles, followed by KI-impregnated cellulose-fibre filters for automated colorimetric analysis of KOH<br>Continuous:<br>• Chemiluminescence<br>• UV absorption (continuous long path or satellite) | Clyne et al. (1964), Clough & Thrush (1967), Werner (1989), Kanno & Yanagisawa (1992), Kleindienst et al. (1993), Koutrakis et al. (1993), Brauer & Brook (1995), Grosjean et al. (1995), Hangartner et al. (1996), Lutter & Wolz (1997), Cox et al. (1999), Cox & Malcolm (1999), Tang & Lau (2000), Boss & Day (2001), Bytnerowicz et al. (2002), Carmichael et al. (2003) |

**Table 1.4 (continued)**

| Observable | Measurement method | References |
|---|---|---|
| Volatile organic compounds (VOCs and SVOCs), including carbonyls, organic acids, alcohols, PAHs, and pesticides (present in gas phase and/or particle phase) | Passive:<br>• Activated charcoal, Tenax, or other thermally desorbed sorbent, followed by GC-MS; can be used to analyse HCs and chlorinated HCs<br>• POPs: started with semipermeable membrane devices (SPMDs), now primarily using PUF disks or XAD-2 resin filled into stainless steel mesh cylinders; samples are extracted in organic solvent before chemical analyses; can be used for PCBs, PBDEs, and other POPs<br>• Pesticides: PUF disk or XAD resin; applied to organochlorine, organophosphate, pyrethrin, triazine, and other PCBs<br>• SVOCs: PUF disks or XAD resin, for PAHs and other organic compounds<br>Integrated:<br>• Canister, bag, or Carbotrap sampling for HCs including $CH_4$, $C_2$–$C_3$, and $C_4$–$C_{10}$, and Tenax for $C_{11}$–$C_{20}$<br>• Filter/PUF or filter/Tenax (US EPA method TO-13) for volatile PAHs<br>• Filter impregnated with DNPH or cryogenic traps for carbonyls<br>• HCHO: mostly with DNPH-coated substrate to form hydrazones, followed by HPLC analysis, or using a Palmes-type tube coated with sodium bisulfite ($NaHSO_3$); method also applied to acetaldehyde, propionaldehyde acetone aldehydes, amines, etc.<br>• Quartz-fibre filters or base-coated filters for organic acids<br>• Charcoal, canister, impinger with water, cryogenic trap, or condensation sampling for alcohols ($C_1$–$C_4$)<br>• Filter/XAD or filter/Tenax (US EPA methods TO-4 and TO-10) for semivolatile pesticides<br>Continuous:<br>• HCs by auto GC-FID for $CH_4$, speciated $C_2$–$C_7$ (including 1,3-butadine), NMHCs including isoprene, $CH_3OH$, $(CH_3)_2CO$, $CH_3CHO$, CO, aldehydes, ketones, alcohols, halocarbons, $N_2O$, PAN, and organic nitrates<br>• Oxygenated HCs by automated GC-FID using selective column<br>• PAN and its homologues (PANs) by CIMS<br>• Carbonyls by electrochemical sensor<br>• NMHCs and oxidized HCs by proton transfer reaction-MS (PTR-MS)<br>• Organic acids by negative-ion CIMS<br>• Organic peroxides by CIMS | NIOSH (1984), Andreae et al. (1987), Shields & Weschler (1987), EPA (1988, 1991), Levin et al. (1988), Cohen et al. (1990), Druzik et al. (1990), Pierotti (1990), Weschler et al. (1990), Zielinska et al. (1990), Zielinska & Fung (1992), Tang et al. (1993), Tanner (1993), Ockenden et al. (1998), Boss & Day (2001), Shoeib & Harner (2002), De Gouw et al. (2003), Rivett et al. (2003), Pozo et al. (2004), Slusher et al. (2004), Crounse et al. (2006), Hamilton et al. (2006), Heard (2006), Santiago & Cayetano (2007), Bohlin et al. (2008), Chaemfa et al. (2008), Gouin et al. (2008), Veres et al. (2008), Chaemfa et al. (2009), He & Balasubramanian (2010), Holzinger et al. (2010), Yatavelli & Thornton (2010), Gębicki et al. (2013) |

**Table 1.4 (continued)**

| Observable | Measurement method | References |
|---|---|---|
| *Multiple gases* | | |
| | • Laser-induced fluorescence (LIF) for OH, NO, $NO_2$, $NO_3^-$, $N_2O$, $SO_2$, CO, and HCHO | Thornton et al. (2000), Matsumoto et al. (2001), Cleary et al. (2002), Day et al. (2002), Thornton et al. (2003) |
| | • Differential optical absorption spectroscopy (DOAS) for NO, $NO_2$, HONO, $NH_3$, $SO_2$, $CS_2$, NMHCs, benzene, toluene, phenol, HCHO, ClO, BrO, $I_2$, etc. | Alicke et al. (2002), Dunlea et al. (2007), Platt et al. (1980), Pundt et al. (2005) |
| | • Cavity ring-down spectroscopy (LAS) for $CH_4$, HCs, NO, $NO_2$, $NO_3$, $N_2O_5$, HONO, Hg, $I_2$, and $O_2$ | Evertsen et al. (2002), Mazurenka et al. (2003), Kebabian et al. (2005), Osthoff et al. (2006) |
| | • Tunable diode LAS including IR absorption (LAS) for CO, $CO_2$, $CH_4$, HCs, liquid water ($H_2O$), $H_2O_2$, NO, $NO_2$, nitric acid ($HNO_3$), $N_2O$, $NH_3$, halocarbons, HCHO, and $O_3$ | Eng et al. (1980), Li et al. (2004) |
| | • Integrated cavity output spectroscopy (ICOS; LAS) for NO, CO, and $CH_4$ | |
| | • FTIR spectroscopy: a vibrational spectroscopy technique for molecular structure and functional groups like $HONO_2$ and HCHO | Behrentz et al. (2004), Clemitshaw (2004), Larkin (2011) |
| | • LIDAR or differential absorption LIDAR (DILA) for NMHCs, $NO_2$, and $O_3$ | Clemitshaw (2004) |
| | • CIMS for OH, $HO_2$, HONO, and $HONO_2$ | Huey et al. (1995), Edwards et al. (2003), Huey (2007) |
| *Particulate matter (PM) for mass and chemical components* | | |
| Mass | Passive:<br>• Dust sampler: collects particles electrostatically with a charged electret; requires knowledge of particle electrical mobility and electret charge<br>• Dust monitor: uses light extinction to estimate index of mass concentration<br>• UNC passive aerosol sampler: developed by the University of North Carolina, USA; based on deposition velocity model; collects particles on a stub by gravity, diffusion, and convective diffusion; followed by SEM or TEM and auto-image analyses to get PM concentration and particle size distribution; may exhibit errors when sampling volatile aerosols; used carbon substrate for SEM or TEM analyses or glass substrate for $PM_{10-2.5}$ (coarse particles) by optical microscopy; uncertainties include assumption of particle density and shape factors, wind speed, turbulence, etc.<br>Integrated:<br>• Peaked-roof sampler for TSP without size-selective inlet for particles of 30–50 µm; integrated samplers for PM include inlet, sampling surfaces, substrates, flow controllers, and pump<br>• $PM_{10}$: using a size-selective inlet with a 50% collection efficiency of 10 µm<br>• $PM_{2.5}$: using a size-selective inlet with a 50% collection efficiency of 2.5 µm | Watson & Chow (1984), Brown & Hemingway (1995), Arashiro & Leith (2013), Brown et al. (1996), Vinzents (1996), Jayne et al. (2000), Wagner & Leith (2001a, b, c), DeCarlo et al. (2006), Leith et al. (2007) |

**Table 1.4 (continued)**

| Observable | Measurement method | References |
|---|---|---|
| Mass (cont.) | • Using filter sampler for TSP, $PM_{10}$, and $PM_{2.5}$ samplers following Federal Reference Method used by US EPA for compliance monitoring. Filters are equilibrated in a temperature-controlled (20–23 °C) and relative humidity-controlled (30–40%) environment for a minimum of 48 hours before pre- and post-gravimetric analysis of filter substrate for mass<br>Continuous:<br>• Measurement by beta attenuation monitor (BAM): based on beta attenuation<br>• Filter dynamics measurement system (FDMS) and tapered element oscillating microbalance (TEOM): based on inertial microbalance<br>• Particle light scattering by nephelometer, a surrogate for $PM_{10}$ or $PM_{2.5}$ mass: particle scattering of visible light, relates scattered intensity to concentration (nephelometer; most often single-wavelength [$\lambda$ = 530 nm] or 3-wavelength [e.g. $\lambda$ = 450, 5258 (or 550), and 635 (or 700) nm]); DustTrak)<br>• AMS for mass of particles with aerodynamic diameters < 1 μm ($PM_1$)<br>• Optical particle counter: measures intensity of individual particle scattering, surrogate for PM mass | |
| Light absorption coefficient ($b_{abs}$); also called absorbance (abs), light absorption, or light transmission | Integrated:<br>• Sampling onto Teflon-membrane filters, usually after gravimetric analysis; densitometer measurement of filter light absorption/light transmission (2-wavelength [$\lambda$ = 370 and 880 nm] transmissometer); or by reflectometer; used as a surrogate for BC | Butterfield et al. (2010), Heal & Quincey (2012) |
| Elements | Integrated (preferably on thin-film Teflon-membrane filter):<br>• XRF: measures ~50 elements from sodium to uranium, except beryllium<br>• Particle-induced X-ray emission (PIXE); part of accelerator-based ion beam analysis (IBA)<br>• Instrumental neutron activation analysis (INAA)<br>• Inductively coupled plasma atomic emission spectroscopy (ICP-AES) or ICP-MS<br>• Flame or graphite AAS (FAAS or GAAS)<br>• Lead by high-volume sampling, followed by acid block or hot plate extraction and AAS analysis (US EPA method 40 CFR Part 50)<br>• Lead by cold trap sampling, followed by analysis by GC-AAS<br>Continuous:<br>• Laser-induced breakdown spectroscopy (LIBS)<br>• XRF filter tape (commercially available, used mostly by industry), measures a limited number of elements<br>• Electron ionization high-resolution MS for elemental species: (C, H, N, S, and O) to determine organic-matter-to-OC ratios | EPA (1982, 2006), Biegalski (1999), Cohen (1999), Grohse (1999), Kasahara (1999), Landsberger & Creatchman (1999), Watson et al. (1999), Lithgow et al. (2004) |

**Table 1.4 (continued)**

| Observable | Measurement method | References |
|---|---|---|
| Ions | Integrated (preferably on quartz-fibre filter):<br>• IC for anions (e.g. $F^-$, $Br^-$, $Cl^-$, $NO_2^-$, $NO_3^-$, $SO_4^{2-}$, and $PO_4^{3-}$) and cations (e.g. $Na^+$, $Mg^{2+}$, $K^+$, $Ca^{2+}$, and $NH_4^+$), can be used to measure $ClO_3^-$, $ClO_2^-$, and $BrO_3^-$<br>• Ion-selective electrode, mainly for $NH_4^+$<br>• Automated colorimetry, mainly for $NH_4^+$; can be analysed for $NO_3^-$ and $SO_4^{2-}$; often on chemically impregnated filters<br>• AAS or GAAS for $Na^+$, $Mg^{2+}$, $K^+$, and $Ca^{2+}$<br>Continuous (measures precursor gases as well as ions):<br>• Field IC: grow particles with steam, then collect precursor gases and multiple ions (e.g. ambient ion monitor [AIM]; PILS; wet annular denuder/steam-jet aerosol collector [MARGA]; gas-particle IC [GPIC]; gas-collector IC; or flash volatilization for $SO_4^{2-}$ and $NO_3^-$ [R&P 8400S and 8400N, respectively; no longer commercialized]); and AMS | Mullin & Riley (1955), Weatherburn (1967), Mulik et al. (1976), Small (1978), Hoffer et al. (1979), Lodge (1989), Chow et al. (1999, 2005, 2008), Grohse (1999), Finlayson-Pitts & Pitts (2000), Jayne et al. (2000), Stolzenburg & Hering (2000), Al-Horr et al. (2003), Weber et al. (2003), Wittig et al. (2004), Trebs et al. (2005), ten Brink et al. (2007), Thomas et al. (2009), Yao et al. (2009), Schaap et al. (2011), Dong et al. (2012) |
| Carbon | Integrated (on quartz-fibre filter):<br>• Thermal methods for OC and EC and their thermal fractions with NDIR detection of $CO_2$: Switzerland two-step method, Lawrence Berkeley Laboratory (LBL) method, Brookhaven National Laboratory (BNL) method, and General Motors (GM) method<br>• Coulometric titration for $CO_2$ by VDI 2465/1, VDI 2465/2, and Centre National de la Recherche Scientifique-Commissariat à l'énergie atomique et aux énergies alternatives (CNRS-CEA) method<br>• Thermal magnesium oxide (TMO) method<br>• Thermal/optical methods for OC and EC; FID detection of $CH_4$; including thermal/optical reflectance (TOR) following the Interagency Monitoring of Protected Visual Environments (IMPROVE_A) protocol that has been applied in long-term non-urban (IMPROVE) and urban (Chemical Speciation Network; CSN) networks in the USA, National Institute for Occupational Safety and Health (NIOSH) thermal/optical transmittance (TOT) protocol, and European Supersites for Atmospheric Aerosol Research (EUSAAR-2) TOT protocol | Cadle et al. (1980), Geisling et al. (1982), Novakov (1982), Cadle et al. (1983), Ellis et al. (1984), Gaffney et al. (1984), Levin et al. (1985), Cachier et al. (1989a), Cachier et al. (1989b), Fung (1990), Chow et al. (1993, 2001, 2004, 2007a, 2011), Birch & Cary (1996a, b), NIOSH (1996), VDI (1996, 1999), Gilpin et al. (1997), Birch (1998), Lavanchy et al. (1999), Kirchstetter et al. (2001), Fung et al. (2002), Watson et al. (2005), Andreae & Gelencser (2006), Seethapathy et al. (2008), Yang et al. (2009), Cavalli et al. (2010), Chakrabarty et al. (2010) |
| Brown carbon | • Various origins at blue or near-UV wavelengths, commonly found in the smouldering phase of biomass burning (e.g. humic-like substances); see: Bioaerosols | |

**Table 1.4 (continued)**

| Observable | Measurement method | References |
|---|---|---|
| Water-soluble organic carbon (WSOC) | • Total organic carbon (TOC) analyser: speciated WSOC classes by HPLC-UV/VIS; IC-pulsed amperometric detection (IC-PAD) for carbohydrates; IC-conductivity detection (IC-CD) for organic acids<br>Continuous:<br>• Semicontinuous real-time carbon aerosol analysis instrument for OC and EC by thermal/optical method<br>• Electron ionization high-resolution MS for non-refractory fraction of OC<br>• PILS for WSOC: combining PILS with total carbon (TC) analyser; can use XAD-8 resin as preceding denuder to separate hydrophobic and hydrophilic carbon fractions<br>• British Smoke/coefficient of haze (COH) for BC: British Smoke quantifies filter darkness by reflectance as air is drawn through; called COH in the USA, light transmission measured based on optical density of filter deposit; reported as COH/1000 linear feet<br>• Filter transmittance (e.g. aethalometer; $\lambda = 370–880$ nm for 2-wavelength, also $\lambda = 370–950$ nm for 7-wavelength); multi-angle absorption photometer (MAAP; $\lambda = 670$ nm)<br>• Single-particle soot absorption photometer ($\lambda = 565$ nm, also $\lambda = 466$, 520, and 660 nm for 3-wavelength) by laser incandescence | Hill (1936), Ingram & Golden (1973), Thornes (1978), Hansen et al. (1984), Brimblecombe (1987), Horvath (1993), Jayne et al. (2000), Weber et al. (2003), Li et al. (2003, 2009), Petzold & Schönlinner (2004), Petzold et al. (2005), DeCarlo et al. (2006), Miyazaki et al. (2006), Park et al. (2006), Sullivan et al. (2006), Sullivan & Weber (2006), Peltier et al. (2007), Slowik et al. (2007), Chow et al. (2009), Kreisberg et al. (2013), Hansen & Mocnik (2010), Lambe et al. (2010), Müller et al. (2011) |
| Reactive oxygen species (ROS) | • Aerosol oxidative activity: couples PILS with microfluidic electrochemical sensor; the oxidative activity is based on dithiothreitol (TDD) assay that assesses the capacity of PM to catalyse ROS generation | |
| Organic speciation | Integrated:<br>• Using filter/PUF/XAD sampling system, followed by solvent extraction-GC (SE-GC) with FID, electron capture detector (ECD), photoionization detector, flame photometric detector (FPD), MS, or TOF-MS for both polar and non-polar organic compounds and volatile halocarbons, NMHCs, aromatics, and PAN; also speciated PAHs<br>• Using an aliquot of filter, followed by direct injection with thermal extraction- or TD-GC-MS for non-polar alkanes, alkenes, cycloalkanes, hopanes, steranes, and PAHs<br>• FTIR for molecular structure and functional groups<br>• HPLC coupled with MS detection, or UV fluorescence: based on water or organic solvent extraction for polar organic compounds or macromolecules<br>• LC with MS detection, or UV fluorescence: for organic fractions such as PAHs, peroxides, carbonyls, and derivatives of organic acids, polymers, and proteins<br>Continuous:<br>• TD aerosol GC/MS-FID (TAG); or auto GC-FID for speciated organic composition of non-polar and polar organic compounds<br>• CIMS for non-polar and polar organic compounds | Vairavamurthy et al. (1992); Rogge et al. (1993); Burtscher & Siegmann (1994), Schauer et al. (1996), Glasius et al. (1999), Schauer & Cass (2000), Sin et al. (2001), Graham et al. (2002), Russell (2003), Welthagen et al. (2003), Ho & Yu (2004), Ward & Smith (2004), William et al. (2006), Chow et al. (2007), Hamilton & Lewis (2007), Hays & Lavrich (2007), Coury & Dillner (2008), Winterhalter et al. (2009), Holzinger et al. (2010), Yatavelli & Thornton (2010) |

**Table 1.4 (continued)**

| Observable | Measurement method | References |
|---|---|---|
| PAHs | • Photoemission aerosol sensor (PAS); photoelectric charging of particles by irradiation with UV light for PAHs of four or more rings | |
| Bioaerosols | Integrated:<br>• Culturable airborne bacteria and fungi: collected using AGI impingers and Andersen impactors, cultivated, and counted on a solid or in a liquid culture medium<br>• Total airborne bacteria and fungi based on: (1) microscopy, including light microscopy (e.g. fluorescence microscopy), electron microscopy, and Raman microscopy; (2) flow cytometry that measures the number of fluorescent biological particles; and (3) qPCR that determines the quantity of DNA copies<br>• Pollens: light microscopy that identifies and enumerates pollen grains collected via non-volumetric (e.g. Durham microscope slides, hanging slides, flags, passive impactor rods, and sticky cylinders) or volumetric (e.g. impactors, cyclones, whirling arm samplers, and Hirst-type samplers such as Burkard pollen and spore traps) sampling approaches<br>• Viruses: qPCR that quantifies the viral DNA/RNA copies; or plaque assays that quantify viral concentrations by infecting living cells with viruses at different dilution ratios<br>• Proteins using micro bicinchoninic acid (BCA) assay, or by nano-orange protein quantification kit<br>• Endotoxins: based on LAL assays with activating factor C, including gel-clot LAL assay, end-point fluorescence assay, end-point chromogenic LAL assay, kinetic chromogenic LAL assay, and kinetic turbidimetric LAL assay; or by GC-MS that measures 3-hydroxyl fatty acids, a key component of endotoxin molecules<br>• (1→3)-β-D-glucan: using inhibition enzyme immunoassay (EIA) or by LAL assays with activating factor G<br>• Mannitol and arabitol: using GC-MS, GC-FID, or by anion-exchange HPLC with pulsed amperometric detection (HPAEC-PAD)<br>• Ergosterol: using HPLC, or by GC-MS<br>• Muramic acid: using GC-MS<br>• Microbial community: based on denaturing gradient gel electrophoresis (DGGE); terminal restriction fragment length polymorphism (T-RFLP); microarrays; clone library sequencing; or pyrosequencing<br>Continuous:<br>• Concentration and size distribution: based on UV aerodynamic particle sizer (UV-APS) and waveband integrated bioaerosol sensor (WIBS) based on the autofluorescence of biomolecules such as nicotinamide adenine dinucleotide phosphate (NADPH) and riboflavin; or by bioaerosol MS that couples fluorescence-based bioaerosol detection with an AMS | Käpylä & Penttinen (1981), Mielniczuk et al. (1993), Douwes et al. (1995), Rantio-Lehtimäki (1995), Douwes et al. (1996), Fox et al. (1996), Terzieva et al. (1996), Hairston et al. (1997), Miller & Young (1997), Mullins & Emberlin (1997), Nielsen et al. (1997), Saraf et al. (1997), Rylander et al. (1999), Bünger et al. (2000), Pashynska et al. (2002), Shelton et al. (2002), Fang et al. (2005), Hogan et al. (2005), Kaye et al. (2005), Maron et al. (2005), An et al. (2006), Brodie et al. (2007), Caseiro et al. (2007), Menetrez et al. (2007), Bauer et al. (2008), Nehme et al. (2008), Vanhee et al. (2008), Chen & Hildemann (2009), Tripathi et al. (2009), Lee et al. (2010), Lindsley et al. (2010), Bowers et al. (2011) |

**Table 1.4 (continued)**

| Observable | Measurement method | References |
|---|---|---|
| *Particle number and size* | | |
| Single particle and particle numbers | Integrated:<br>• Sampling onto polycarbonate paper, followed by SEM<br>• Sampling onto TEM grid, followed by TEM | Fruhstorfer & Niessner (1994), Adachi et al. (2007), Tumolva et al. (2010) |
| Particle size distribution | • Use cascade impactors such as micro-orifice uniform deposit impactor (MOUDI) or electrical low-pressure impactor (ELPI) for particle size distribution on filter substrates | Watson & Chow (2013) |
| | Continuous:<br>• Condensation particle counter (CPC)<br>• Scanning mobility particle sizer (SMPS), aerosol particle sizer, or optical particle counters for particle size distribution<br>• AMS uses single particle laser ablation based on laser vaporization, laser-induced plasma, or multiphoton ionization<br>• Aerosol TOF-MS | Noble & Prather (1996), McMurry (2000b), Gebhart (2001), DeCarlo et al. (2006), Binnig et al. (2007), Spencer et al. (2007), Park et al. (2008), Giechaskiel et al. (2009), Grimm & Eatough (2009), Takegawa et al. (2009), Wang et al. (2009, 2010b), Farmer & Jimenez (2010), Giechaskiel & Bergmann (2011) |
| *Mercury* | | |
| | Integrated:<br>• Atmospheric mercury is present in three forms: GEM, largely present in the atmosphere; RGM; and reactive Hg-P; sampling train includes quartz-fibre filter for Hg-P, KCl-impregnated filter for RGM, and gold trap for GEM; samples are subjected to thermal mercury analysis: thermal extraction followed by gold amalgamation and cold vapour atomic fluorescence spectroscopy (CVAFS) | Lin & Pehkonen (1999), Rutter & Schauer (2007), Witt et al. (2010) |
| | Continuous:<br>• Total mercury speciated by oxidation: measured by atomic fluorescence and UV photometry | |

AAS, atomic absorption spectroscopy; AMS, aerosol mass spectrometer; BC, black carbon; $CH_4$, methane; CIMS, chemical ionization mass spectrometry; CO, carbon monoxide; $CO_2$, carbon dioxide; DNPH, 2,4-dinitrophenylhydrazone; EC, elemental carbon; FID, flame ionization detector; FTIR, Fourier transform infrared; GAAS, graphite atomic absorption spectroscopy; GC, gas chromatography; GEM, gaseous elemental mercury; HCHO, formaldehyde; HCs, hydrocarbons; Hg-P, particulate mercury; HONO, nitrous acid; HPLC, high-performance liquid chromatography; IC, ion chromatography; IR, infrared; KI, potassium iodide; LAL, *Limulus* amoebocyte lysate; LAS, laser absorption spectroscopy; LC, liquid chromatography; LIDAR, light detection and ranging; MS, mass spectrometry; NDIR, non-dispersive infrared; NMHCs, non-methane hydrocarbons; NO, nitrogen oxide; $NO_2$, nitrogen dioxide; $NO_x$, nitrogen oxides; $N_2O$, nitrous oxide; $O_3$, ozone; OC, organic carbon; PAHs, polycyclic aromatic hydrocarbons; PAN, peroxyacetyl nitrate; PBDEs, polybrominated diphenyl ethers; PCBs, polychlorinated biphenyls; PILS, particle-into-liquid sampler; PM, particulate matter; $PM_{10}$, particulate matter with particles of aerodynamic diameter < 10 µm; $PM_{2.5}$, particulate matter with particles of aerodynamic diameter < 2.5 µm; POPs, persistent organic pollutants; PUF, polyurethane foam; qPCR, quantitative real-time polymerase chain reaction; RGM, reactive gaseous mercury; ROS, reactive oxygen species; SEM, scanning electron microscopy; $SO_2$, sulfur dioxide; SVOCs, semivolatile organic compounds; TD, thermal desorption; TEA, triethanolamine; TEM, transmission electron microscopy; TOF-MS, time-of-flight mass spectrometry; TSP, total suspended particles; US EPA, United States Environmental Protection Agency; UV, ultraviolet; VIS, visible; VOCs, volatile organic compounds; WSOC, water-soluble organic carbon; XRF, X-ray fluorescence.
Prepared by the Working Group.

## References


Abi Esber L, El-Fadel M, Shihadeh A (2007). Comparison of trip average in-vehicle and exterior CO determinations by continuous and grab sampling using an electrochemical sensing method. *Atmos Environ*, 41(28):6087–94. doi:10.1016/j.atmosenv.2007.05.020

Adachi K, Chung SH, Friedrich H, Buseck PR (2007). Fractal parameters of individual soot particles determined using electron tomography: implications for optical properties. *J Geophys Res Atmos*, 112(D14): D14202. doi:10.1029/2006JD008296

Al-Horr R, Samanta G, Dasgupta PK (2003). A continuous analyzer for soluble anionic constituents and ammonium in atmospheric particulate matter. *Environ Sci Technol*, 37(24):5711–20. doi:10.1021/es034464j PMID:14717184

Alicke B, Platt U, Stutz J (2002). Impact of nitrous acid photolysis on the total hydroxyl radical budget during the Limitation of Oxidant Production/Pianura Padana Produzione di Ozono study in Milan. *J Geophys Res Atmos*, 107(D22):8196. doi:10.1029/2000JD000075

An HR, Mainelis G, White L (2006). Development and calibration of real-time PCR for quantification of airborne microorganisms in air samples. *Atmos Environ*, 40(40):7924–39. doi:10.1016/j.atmosenv.2006.07.020

Andreae MO, Gelencser A (2006). Black carbon or brown carbon? The nature of light-absorbing carbonaceous aerosols. *Atmos Chem Phys*, 6(10):3131–48. doi:10.5194/acp-6-3131-2006

Andreae MO, Talbot RW, Li SM (1987). Atmospheric measurements of pyruvic and formic acid. *J Geophys Res Atmos*, 92(D6):6635–41. doi:10.1029/JD092iD06p06635

Arashiro M, Leith D (2013). Precision of PM measurements with the UNC passive aerosol sampler. *J Aerosol Sci*, 57:181–4. doi:10.1016/j.jaerosci.2012.09.001

Atkins DHF, Sandalls J, Law DV, Hough AM, Stevenson K (1986). The measurement of nitrogen dioxide in the outdoor environment using passive diffusion tube samplers. AERE R12133. Harwell, UK: United Kingdom Atomic Energy Authority.

Bauer H, Claeys M, Vermeylen R, Schueller E, Weinke G, Berger A et al. (2008). Arabitol and mannitol as tracers for the quantification of airborne fungal spores. *Atmos Environ*, 42(3):588–93. doi:10.1016/j.atmosenv.2007.10.013

Beghi M, Mari CM, Pizzini S (1987). Electrochemical sensors for $SO_2$ determination in $SO_2$ air mixtures. *J Electrochem Soc*, 134 (Abstract:1657) (8-B):521C.

Behrentz E, Ling R, Rieger P, Winer AM (2004). Measurements of nitrous oxide emissions from light-duty motor vehicles: a pilot study. *Atmos Environ*, 38(26):4291–303. doi:10.1016/j.atmosenv.2004.04.027

Benedict AF, Reiszner KD, West PW (1983). A personal ammonia monitor utilizing permeation sampling *AIHA J (Fairfax, Va)*, 44(1):66–70.

Bhoga SS, Singh K (2007). Electrochemical solid state gas sensors: an overview. *Ionics*, 13(6):417–27. doi:10.1007/s11581-007-0150-7

Biegalski SR (1999). Quality assurance and quality control in the elemental analysis of airborne particles. In: Landsberger S, Creatchman M, editors. Elemental analysis of airborne particles. Amsterdam, The Netherlands: Gordon and Breach Science; pp. 255–71.

Binnig J, Meyer J, Kasper G (2007). Calibration of an optical particle counter to provide mass for well-defined particle materials. *J Aerosol Sci*, 38(3):325–32. doi:10.1016/j.jaerosci.2006.12.001

Birch ME (1998). Analysis of carbonaceous aerosols: interlaboratory comparison. *Analyst (Lond)*, 123(5):851–7. doi:10.1039/a800028j PMID:9709478

Birch ME, Cary RA (1996a). Elemental carbon-based method for occupational monitoring of particulate diesel exhaust: methodology and exposure issues. *Analyst (Lond)*, 121(9):1183–90. doi:10.1039/an9962101183 PMID:8831275

Birch ME, Cary RA (1996b). Elemental carbon-based method for monitoring occupational exposures to particulate diesel exhaust. *Aerosol Sci Technol*, 25(3):221–41. doi:10.1080/02786829608965393

Blatter A, Fahrni M, Neftel A (1992). A new generation of NH3 passive samplers. In: Allegrini I, editor. Development of analytical techniques for atmospheric pollutants. EC Air Pollution Research Report 41. Brussels, Belgium: Commission of the European Communities.

Bogue R (2008). Environmental sensing: strategies, technologies and applications. *Sensor Rev*, 28(4):275–82. doi:10.1108/02602280810902550

Bohlin P, Jones KC, Tovalin H, Strandberg B (2008). Observations on persistent organic pollutants in indoor and outdoor air using passive polyurethane foam samplers. *Atmos Environ*, 42(31):7234–41. doi:10.1016/j.atmosenv.2008.07.012

Boss MJ, Day DW (2001). *Air sampling and industrial hygiene engineering*. Boca Raton (FL): Lewis Publishers.

Bowers RM, McLetchie S, Knight R, Fierer N (2011). Spatial variability in airborne bacterial communities across land-use types and their relationship to the bacterial communities of potential source environments. *ISME J*, 5(4):601–12. doi:10.1038/ismej.2010.167 PMID:21048802

Brauer M, Brook JR (1995). Personal and fixed-site ozone measurements with a passive sampler. *J Air Waste Manag Assoc*, 45(7):529–37. doi:10.1080/10473289.1995.10467384 PMID:7634124

Brimblecombe P (1987). The big smoke: a history of air pollution in London since medieval times. London: Methuen & Co. Ltd.

Brodie EL, DeSantis TZ, Parker JP, Zubietta IX, Piceno YM, Andersen GL (2007). Urban aerosols harbor diverse and dynamic bacterial populations. *Proc Natl Acad Sci U S A*, 104(1):299–304. doi:10.1073/pnas.0608255104 PMID:17182744

Brown RC, Hemingway MA (1995). Measurement of the electrical mobility of aerosols using an electret with spatially variable charge: theory and experiment. *J Electrost*, 34(1):87–101. doi:10.1016/0304-3886(94)00043-V

Brown RC, Hemingway MA, Wake D, Thorpe A (1996). Electret-based passive dust sampler: sampling of organic dusts. *Analyst (Lond)*, 121(9):1241–6. doi:10.1039/an9962101241 PMID:8831282

Bünger J, Krahl J, Baum K, Schröder O, Müller M, Westphal G et al. (2000). Cytotoxic and mutagenic effects, particle size and concentration analysis of diesel engine emissions using biodiesel and petrol diesel as fuel. *Arch Toxicol*, 74(8):490–8. doi:10.1007/s002040000155 PMID:11097388

Burtscher H, Siegmann HC (1994). Monitoring PAH-emissions from combustion processes by photoelectric charging. *Combust Sci Technol*, 101(1–6):327–32. doi:10.1080/00102209408951880

Butterfield DM, Beccaceci S, Sweeney B, Green D, Alexander J, Grieve A (2010). 2009 Annual report for the UK Black Carbon Network. NPL Report A5 52. Teddington, UK: National Physics Laboratory.

Bytnerowicz A, Godzik B, Fraczek W, Grodzińska K, Krywult M, Badea O et al. (2002). Distribution of ozone and other air pollutants in forests of the Carpathian Mountains in central Europe. *Environ Pollut*, 116(1):3–25. doi:10.1016/S0269-7491(01)00187-7 PMID:11808553

Cachier H, Bremond MP, Buat-Ménard P (1989a). Determination of atmospheric soot carbon with a simple thermal method. *Tellus*, 41B(3):379–90. doi:10.1111/j.1600-0889.1989.tb00316.x

Cachier H, Bremond MP, Buat-Ménard P (1989b). Thermal separation of soot carbon. *Aerosol Sci Technol*, 10(2):358–64. doi:10.1080/02786828908959273

Cadle SH, Groblicki PJ, Mulawa PA (1983). Problems in the sampling and analysis of carbon particulate *Atmos Environ (1967)*, 17(3):593–600. doi:10.1016/0004-6981(83)90132-4

Cadle SH, Groblicki PJ, Stroup DP (1980). Automated carbon analyzer for particulate samples. *Anal Chem*, 52(13):2201–6. doi:10.1021/ac50063a047

Carmichael GR, Ferm M, Thongboonchoo N, Woo J-H, Chan LY, Murano K et al. (2003). Measurements of sulfur dioxide, ozone and ammonia concentrations in Asia, Africa, and South America using passive samplers. *Atmos Environ*, 37(9–10):1293–308. doi:10.1016/S1352-2310(02)01009-9

Caseiro A, Marr IL, Claeys M, Kasper-Giebl A, Puxbaum H, Pio CA (2007). Determination of saccharides in atmospheric aerosol using anion-exchange high-performance liquid chromatography and pulsed-amperometric detection. *J Chromatogr A*, 1171(1–2):37–45. doi:10.1016/j.chroma.2007.09.038 PMID:17920614

Cavalli F, Viana M, Yttri KE, Genberg J, Putaud J-P (2010). Toward a standardised thermal-optical protocol for measuring atmospheric organic and elemental carbon: the EUSAAR protocol. *Atmos Meas Tech*, 3(1):79–89. doi:10.5194/amt-3-79-2010

Chaemfa C, Barber JL, Gocht T, Harner T, Holoubek I, Klanova J et al. (2008). Field calibration of polyurethane foam (PUF) disk passive air samplers for PCBs and OC pesticides. *Environ Pollut*, 156(3):1290–7. doi:10.1016/j.envpol.2008.03.016 PMID:18474408

Chaemfa C, Barber JL, Kim KS, Harner T, Jones KC (2009). Further studies on the uptake of persistent organic pollutants (POPs) by polyurethane foam disk passive air samplers. *Atmos Environ*, 43(25):3843–9. doi:10.1016/j.atmosenv.2009.05.020

Chakrabarty RK, Moosmüller H, Chen L-WA, Lewis K, Arnott WP, Mazzoleni C et al. (2010). Brown carbon in tar balls from smoldering biomass combustion. *Atmos Chem Phys*, 10(13):6363–70. doi:10.5194/acp-10-6363-2010

Chang SC, Stetter JR (1990). Electrochemical $NO_2$ gas sensors: model and mechanism for the electroreduction of $NO_2$. *Electroanalysis*, 2(5):359–65. doi:10.1002/elan.1140020506

Chen Q, Hildemann LM (2009). Size-resolved concentrations of particulate matter and bioaerosols inside versus outside of homes. *Aerosol Sci Technol*, 43(7):699–713. doi:10.1080/02786820902882726

Chow JC, Doraiswamy P, Watson JG, Chen LW, Ho SS, Sodeman DA (2008). Advances in integrated and continuous measurements for particle mass and chemical composition. *J Air Waste Manag Assoc*, 58(2):141–63. doi:10.3155/1047-3289.58.2.141 PMID:18318335

Chow JC, Watson JG, Chen LW, Arnott WP, Moosmüller H, Fung K (2004). Equivalence of elemental carbon by thermal/optical reflectance and transmittance with different temperature protocols. *Environ Sci Technol*, 38(16):4414–22. doi:10.1021/es034936u PMID:15382872

Chow JC, Watson JG, Chen LW, Chang MC, Robinson NF, Trimble D et al. (2007a). The IMPROVE_A temperature protocol for thermal/optical carbon analysis: maintaining consistency with a long-term database. *J Air Waste Manag Assoc*, 57(9):1014–23. doi:10.3155/1047-3289.57.9.1014 PMID:17912920

Chow JC, Watson JG, Crow D, Lowenthal DH, Merrifield T (2001). Comparison of IMPROVE and NIOSH carbon measurements. *Aerosol Sci Technol*, 34(1):23–34. doi:10.1080/02786820119073

Chow JC, Watson JG, Doraiswamy P, Chen L-WA, Sodeman DA, Lowenthal DH et al. (2009). Aerosol light absorption, black carbon, and elemental carbon at the

Fresno Supersite, California. *Atmos Res*, 93(4):874–93. doi:10.1016/j.atmosres.2009.04.010

Chow JC, Watson JG, Green MC, Lowenthal DH, DuBois DW, Kohl SD et al. (1999). Middle- and neighborhood-scale variations of $PM_{10}$ source contributions in Las Vegas, Nevada. *J Air Waste Manag Assoc*, 49(6):641–54. doi:10.1080/10473289.1999.10463837

Chow JC, Watson JG, Lowenthal DH, Magliano KL (2005). Loss of $PM_{2.5}$ nitrate from filter samples in central California. *J Air Waste Manag Assoc*, 55(8):1158–68. doi:10.1080/10473289.2005.10464704 PMID:16187585

Chow JC, Watson JG, Pritchett LC, Pierson WR, Frazier CA, Purcell RG (1993). The DRI thermal/optical reflectance carbon analysis system: description, evaluation and applications in U.S. air quality studies. *Atmos Environ*, 27A(8):1185–201. doi:10.1016/0960-1686(93)90245-T

Chow JC, Watson JG, Robles J, Wang X, Chen LW, Trimble DL et al. (2011). Quality assurance and quality control for thermal/optical analysis of aerosol samples for organic and elemental carbon. *Anal Bioanal Chem*, 401(10):3141–52. doi:10.1007/s00216-011-5103-3 PMID:21626190

Chow JC, Yu JZ, Watson JG, Ho SS, Bohannan TL, Hays MD et al. (2007). The application of thermal methods for determining chemical composition of carbonaceous aerosols: a review. *J Environ Sci Health Part A Tox Hazard Subst Environ Eng*, 42(11):1521–41. doi:10.1080/10934520701513365

Cleary PA, Wooldridge PJ, Cohen RC (2002). Laser-induced fluorescence detection of atmospheric $NO_2$ with a commercial diode laser and a supersonic expansion. *Appl Opt*, 41(33):6950–6. doi:10.1364/AO.41.006950 PMID:12463239

Clemitshaw KC (2004). A review of instrumentation and measurement techniques for ground-based and airborne field studies of gas-phase tropospheric chemistry. *Crit Rev Environ Sci Technol*, 34(1):1–108. doi:10.1080/10643380490265117

Clough PN, Thrush BA (1967). Mechanism of chemiluminescent reaction between nitric oxide and ozone. *Trans Faraday Soc*, 63:915–25. doi:10.1039/tf9676300915

Clyne MAA, Thrush BA, Wayne RP (1964). Kinetics of the chemiluminescent reaction between nitric oxide and ozone. *Trans Faraday Soc*, 60:359–70. doi:10.1039/tf9646000359

Cohen DD (1999). Accelerator based ion beam techniques for trace element aerosol analysis. In: Landsberger S, Creatchman M, editors. Elemental analysis of airborne particles. Amsterdam, The Netherlands: Gordon and Breach Science; pp. 139–96.

Cohen DD, Garton D, Stelcer E (2000). Multi-elemental methods for fine particle source apportionment at the global baseline station at Cape Grim, Tasmania. *Nucl Instrum Methods Phys Res B*, 161:775–9.

Cohen MA, Ryan PB, Yanagisawa Y, Hammond SK (1990). The validation of a passive sampler for indoor and outdoor concentrations of volatile organic compounds. *J Air Waste Manage Assoc*, 40(7):993–7. doi:10.1080/10473289.1990.10466751 PMID:2378742

Coury C, Dillner AM (2008). A method to quantify organic functional groups and inorganic compounds in ambient aerosols using attenuated total reflectance FTIR spectroscopy and multivariate chemometric techniques. *Atmos Environ*, 42(23):5923–32. doi:10.1016/j.atmosenv.2008.03.026

Cox LH, Guttorp P, Sampson PD, Caccia DC, Thompson ML (1999). A preliminary statistical examination of the effects of uncertainty and variability on environmental regulatory criteria for ozone. *Novartis Found Symp*, 220:122–38, discussion 138–43. doi:10.1002/9780470515600.ch7 PMID:10231828

Cox RM (2003). The use of passive sampling to monitor forest exposure to $O_3$, $NO_2$ and $SO_2$: a review and some case studies. *Environ Pollut*, 126(3):301–11. doi:10.1016/S0269-7491(03)00243-4 PMID:12963291

Cox RM, Malcolm JW (1999). Passive ozone monitoring for forest health assessment. *Water Air Soil Pollut*, 116(1–2):339–44. doi:10.1023/A:1005285026276

Crounse JD, McKinney KA, Kwan AJ, Wennberg PO (2006). Measurement of gas-phase hydroperoxides by chemical ionization mass spectrometry. *Anal Chem*, 78(19):6726–32. doi:10.1021/ac0604235 PMID:17007490

Day DA, Wooldridge PJ, Dillon MB, Thornton JA, Cohen RC (2002). A thermal dissociation laser-induced fluorescence instrument for in situ detection of $NO_2$, peroxy nitrates, alkyl nitrates, and $HNO_3$. *J Geophys Res Atmos*, 107(D6):ACH 4–1–ACH 4–14.

De Gouw J, Warneke C, Karl T, Eerdekens G, van der Veen C, Fall R (2003). Sensitivity and specificity of atmospheric trace gas detection by proton-transfer-reaction mass spectrometry. *Int J Mass Spectrom*, 223–224:365–82. doi:10.1016/S1387-3806(02)00926-0

DeCarlo PF, Kimmel JR, Trimborn A, Northway MJ, Jayne JT, Aiken AC et al. (2006). Field-deployable, high-resolution, time-of-flight aerosol mass spectrometer. *Anal Chem*, 78(24):8281–9. doi:10.1021/ac061249n PMID:17165817

Demerjian KL (2010). A review of national monitoring networks in North America. *Atmos Environ*, 34(12–14):1861–84.

Deshler T, Mercer JL, Smit HGJ, Stubi R, Levrat G, Johnson BJ et al. (2008). Atmospheric comparison of electrochemical cell ozonesondes from different manufacturers, and with different cathode solution strengths: the Balloon Experiment on Standards for Ozonesondes. *J Geophys Res Atmos*, 113(D4):D04307. doi:10.1029/2007JD008975

Dong HB, Zeng LM, Hu M, Wu YS, Zhang YH, Slanina J et al. (2012). Technical Note: The application of an improved gas and aerosol collector for ambient air

pollutants in China. *Atmos Chem Phys*, 12(21):10519–33. doi:10.5194/acp-12-10519-2012

Douwes J, Doekes G, Montijn R, Heederik D, Brunekreef B (1996). Measurement of β(1→3)-glucans in occupational and home environments with an inhibition enzyme immunoassay. *Appl Environ Microbiol*, 62(9):3176–82. PMID:8795207

Douwes J, Versloot P, Hollander A, Heederik D, Doekes G (1995). Influence of various dust sampling and extraction methods on the measurement of airborne endotoxin. *Appl Environ Microbiol*, 61(5):1763–9. PMID:7646014

Druzik CM, Grosjean D, Van Neste A, Parmar SS (1990). Sampling of atmospheric carbonyls with small DNPH-coated C18 cartridges and liquid chromatography analysis with diode array detection. *Int J Environ Anal Chem*, 38(4):495–512. doi:10.1080/03067319008026952

Dunlea EJ, Herndon SC, Nelson DD, Volkamer RM, San Martini F, Sheehy PM et al. (2007). Evaluation of nitrogen dioxide chemiluminescence monitors in a polluted urban environment. *Atmos Meas Tech*, 7:2691–704.

Edwards GD, Cantrell CA, Stephens S, Hill B, Goyea O, Shetter RE et al. (2003). Chemical ionization mass spectrometer instrument for the measurement of tropospheric $HO_2$ and $RO_2$. *Anal Chem*, 75(20):5317–27. doi:10.1021/ac034402b PMID:14710808

Ellis EC, Novakov T, Zeldin MD (1984). Thermal characterization of organic aerosols. *Sci Total Environ*, 36:261–70. doi:10.1016/0048-9697(84)90275-4

Eng RS, Butler JF, Linden KJ (1980). Tunable diode laser spectroscopy: an invited review. *Opt Eng*, 19(6):945–60. doi:10.1117/12.7972642

EPA (1982). Reference method for the determination of suspended particulate matter in the atmosphere (high-volume method) – 40 CFR Part 50. *Fed Regist*, 47(234):54912

EPA (1988). TO1 to TO14. In: Compendium of methods for the determination of toxic organic compounds in ambient air. EPA/600/4–89/017. Research Triangle Park (NC): US Environmental Protection Agency.

EPA (1991). Technical assistance document for sampling and analysis of ozone precursors. EPA 600/8–91/215. Research Triangle Park (NC): US Environmental Protection Agency.

EPA (2006). Report on air quality in nonattainment areas for 2003–2005 covering ozone, particulate matter, carbon monoxide, sulfur dioxide, nitrogen dioxide, and lead. Research Triangle Park (NC): US Environmental Protection Agency.

EPA (2010). Ambient concentrations of lead. Research Triangle Park (NC): US Environmental Protection Agency. Available from: http://www2.epa.gov/air/airtrends/lead.html, accessed 17 September 2014.

Evertsen R, Staicu A, Dam N, van Vliet A, Ter Meulen JJ (2002). Pulsed cavity ring-down spectroscopy of NO and $NO_2$ in the exhaust of a diesel engine. *Appl Phys B*, 74(4–5):465–8. doi:10.1007/s003400200828

Fang GC, Wu YS, Chen JC, Fu PP, Chang CN, Ho TT et al. (2005). Characteristic study of polycyclic aromatic hydrocarbons for fine and coarse particulates at Pastureland near Industrial Park sampling site of central Taiwan. *Chemosphere*, 60(3):427–33. doi:10.1016/j.chemosphere.2004.12.034 PMID:15924963

Farmer DK, Jimenez JL (2010). Real-time atmospheric chemistry field instrumentation. *Anal Chem*, 82(19):7879–84. doi:10.1021/ac1010603 PMID:20722374

Ferm M, Sjodin A (1993). Proposal of an impregnated filter technique for monitoring of NO2 at EMEP stations. In: EMP Workshop on Measurements of Nitrogen-Containing Compounds, Les Diablerets, Switzerland, July 1992. EMEP/CCC-Report 1/93. Lillestrøm, Norway: Chemical Coordination Centre, Norwegian Institute for Air Research.

Ferm M, Svanberg PA (1998). Cost-efficient techniques for urban- and background measurements of $SO_2$ and $NO_2$. *Atmos Environ*, 32(8):1377–81. doi:10.1016/S1352-2310(97)00170-2

Finlayson-Pitts BJ, Pitts JN (2000). Analytical methods and typical atmospheric concentrations for gases and particles. Chapter 11. In: Finlayson-Pitts BJ, Pitts JN, editors. Chemistry of the upper and lower atmosphere. San Diego (CA): Academic Press; pp. 547–656. doi:10.1016/B978-012257060-5/50013-7

Fox A, Krahmer M, Harrelson D (1996). Monitoring muramic acid in air (after alditol acetate derivatization) using a gas chromatograph-ion trap tandem mass spectrometer. *J Microbiol Methods*, 27(2–3):129–38. doi:10.1016/S0167-7012(96)00939-6

Fruhstorfer P, Niessner R (1994). Identification and classification of airborne soot particles using an automated SEM/EDX. *Mikrochim Acta*, 113(3–6):239–50. doi:10.1007/BF01243614

Fung K (1990). Particulate carbon speciation by $MnO_2$ oxidation. *Aerosol Sci Technol*, 12(1):122–7. doi:10.1080/02786829008959332

Fung K, Chow JC, Watson JG (2002). Evaluation of OC/EC speciation by thermal manganese dioxide oxidation and the IMPROVE method. *J Air Waste Manag Assoc*, 52(11):1333–41. doi:10.1080/10473289.2002.10470867 PMID:12469720

Gaffney JS, Marley NA, Steele HD, Drayton PJ, Hubbe JM (1999). Aircraft measurements of nitrogen dioxide and peroxyacyl nitrates using luminol chemiluminescence with fast capillary gas chromatography. *Environ Sci Technol*, 33(19):3285–9. doi:10.1021/es981102g

Gaffney JS, Tanner RL, Phillips M (1984). Separating carbonaceous aerosol source terms using thermal evolution, carbon isotopic measurements, and C/N/S determinations. *Sci Total Environ*, 36:53–60. doi:10.1016/0048-9697(84)90247-X

Gebhart J (2001). Optical direct-reading techniques: light intensity systems. In: Baron P, Willeke K, editors. Aerosol measurement: principles, techniques, and applications. New York: John Wiley & Sons; pp. 419–54.

Gębicki J, Kloskowski A, Chrzanowski W (2013). Prototype of electrochemical sensor for measurements of volatile organic compounds in gases. *Sens Actuators B Chem*, 177:1173–9. doi:10.1016/j.snb.2012.12.025

Geisling KL, Miksch RR, Rappaport SM (1982). Generation of dry formaldehyde at trace levels by the vapor-phase depolymerization of trioxane. *Anal Chem*, 54(1):140–2. doi:10.1021/ac00238a042

Giechaskiel B, Bergmann A (2011). Validation of 14 used, re-calibrated and new TSI 3790 condensation particle counters according to the UN-ECE Regulation 83. *J Aerosol Sci*, 42(3):195–203. doi:10.1016/j.jaerosci.2011.01.002

Giechaskiel B, Wang X, Horn HG, Spielvogel J, Gerhart C, Southgate J et al. (2009). Calibration of condensation particle counters for legislated vehicle number emission measurements. *Aerosol Sci Technol*, 43(12):1164–73. doi:10.1080/02786820903242029

Gilpin TE, Fried A, Wert B, Calvert J, Genfa Z, Dasgupta P et al. (1997). Intercomparison of six ambient [$CH_2O$] measurement techniques. *J Geophys Res Atmos*, 102(D17):21,161–21,188.

Glasius M, Duane M, Larsen BR (1999). Determination of polar terpene oxidation products in aerosols by liquid chromatography — ion trap mass spectrometry. *J Chromatogr A*, 833(2):121–35. doi:10.1016/S0021-9673(98)01042-5

Gouin T, Wania F, Ruepert C, Castillo LE (2008). Field testing passive air samplers for current use pesticides in a tropical environment. *Environ Sci Technol*, 42(17):6625–30. doi:10.1021/es8008425 PMID:18800540

Graham B, Mayol-Bracero OL, Guyon P, Roberts GC, Decesari S, Facchini MC et al. (2002). Water-soluble organic compounds in biomass burning aerosols over Amazonia 1. Characterization by NMR and GC-MS. *J Geophys Res Atmos*, 107(D20):8047. doi:10.1029/2001JD000336

Grimm H, Eatough DJ (2009). Aerosol measurement: the use of optical light scattering for the determination of particulate size distribution, and particulate mass, including the semi-volatile fraction. *J Air Waste Manag Assoc*, 59(1):101–7. doi:10.3155/1047-3289.59.1.101 PMID:19216193

Grohse PM (1999). Trace element analysis of airborne particles by atomic absorption spectroscopy, inductively coupled plasma-atomic emission spectroscopy, and inductively coupled plasma-mass spectrometry. In: Landsberger S, Creatchman M, editors. Elemental analysis of airborne particles. Amsterdam, The Netherlands: Gordon and Breach Science; pp. 1–65.

Grosjean D, Williams EL 2nd, Grosjean E (1995). Monitoring ambient ozone with a network of passive samplers: a feasibility study. *Environ Pollut*, 88(3):267–73. doi:10.1016/0269-7491(95)93439-7 PMID:15091538

Hairston PP, Ho J, Quant FR (1997). Design of an instrument for real-time detection of bioaerosols using simultaneous measurement of particle aerodynamic size and intrinsic fluorescence. *J Aerosol Sci*, 28(3):471–82. doi:10.1016/S0021-8502(96)00448-X PMID:11540539

Hallberg BO, Rudling JAN (1989). A diffusive sampler of gaseous pollutants by collection in liquid media. *Ann Occup Hyg*, 33(1):61–8. doi:10.1093/annhyg/33.1.61

Hamilton JF, Lewis AC (2007). Chromatographic methods. In: Heard D, editor. Analytical techniques for atmospheric measurement. Oxford, UK: Blackwell Publishing; pp. 361–405.

Hamilton JF, Lewis AC, Reynolds JC, Carpenter LJ, Lubben A (2006). Investigating the composition of organic aerosol resulting from cyclohexene ozonolysis: low molecular weight and heterogeneous reaction products. *Atmos Meas Tech*, 6:4973–84.

Hangartner M, Kirchner M, Werner H (1996). Evaluation of passive methods for measuring ozone in the European Alps. *Analyst (Lond)*, 121(9):1269–72. doi:10.1039/an9962101269

Hansen ADA, Mocnik G (2010). The "Micro" Aethalometer(R): an enabling technology for new applications in the measurement of aerosol black carbon. In: Chow JC, Watson JG, Cao JJ, editors. Proceedings: Leapfrogging opportunities for air quality improvement. Pittsburgh (PA): Air & Waste Management Association; pp. 984–9.

Hansen ADA, Rosen H, Novakov T (1984). The aethalometer – an instrument for the real-time measurement of optical absorption by aerosol particles. *Sci Total Environ*, 36:191–6. doi:10.1016/0048-9697(84)90265-1

Hays MD, Lavrich RJ (2007). Developments in direct thermal extraction gas chromatography-mass spectrometry of fine aerosols. *Trends Analyt Chem*, 26(2):88–102. doi:10.1016/j.trac.2006.08.007

He J, Balasubramanian R (2010). A comparative evaluation of passive and active samplers for measurements of gaseous semi-volatile organic compounds in the tropical atmosphere. *Atmos Environ*, 44(7):884–91. doi:10.1016/j.atmosenv.2009.12.009

Heal MR, Quincey P (2012). The relationship between black carbon concentration and black smoke: a more general approach. *Atmos Environ*, 54(0):538–44. doi:10.1016/j.atmosenv.2012.02.067

Heard MJ (2006). *Analytical techniques for atmospheric measurement*. Oxford, UK: Blackwell Publishing. doi:10.1002/9780470988510

Hill ASG (1936). Measurement of the optical densities of smokestains of filter papers. *Trans Faraday Soc*, 32:1125–31. doi:10.1039/tf9363201125

Ho SS, Yu JZ (2004). In-injection port thermal desorption and subsequent gas chromatography-mass spectrometric analysis of polycyclic aromatic hydrocarbons and n-alkanes in atmospheric aerosol samples. *J Chromatogr A*, 1059(1–2):121–9. doi:10.1016/j.chroma.2004.10.013 PMID:15628132

Hoffer T, Kliwer J, Moyer J (1979). Sulfate concentrations in the southwestern desert of the United States *Atmos Environ (1967)*, 13(5):619–27. doi:10.1016/0004-6981(79)90190-2

Hogan CJ Jr, Kettleson EM, Lee MH, Ramaswami B, Angenent LT, Biswas P (2005). Sampling methodologies and dosage assessment techniques for submicrometre and ultrafine virus aerosol particles. *J Appl Microbiol*, 99(6):1422–34. doi:10.1111/j.1365-2672.2005.02720.x PMID:16313415

Holzinger R, Kasper-Giebl A, Staudinger M, Schauer G, Rockmann T (2010). Analysis of the chemical composition of organic aerosol at the Mt. Sonnblick observatory using a novel high mass resolution thermal-desorption proton-transfer-reaction mass-spectrometer (hr-TD-PTR-MS). *Atmos Chem Phys*, 10(20):10111–28. doi:10.5194/acp-10-10111-2010

Horvath H (1993). Comparison of measurements of aerosol optical absorption by filter collection and a transmissometric method. *Atmos Environ Part A Gen Topics*, 27A(3):319–25. doi:10.1016/0960-1686(93)90105-8

Huey LG (2007). Measurement of trace atmospheric species by chemical ionization mass spectrometry: speciation of reactive nitrogen and future directions. *Mass Spectrom Rev*, 26(2):166–84. doi:10.1002/mas.20118 PMID:17243143

Huey LG, Hanson DR, Howard CJ (1995). Reactions of $SF_6^-$ and $I^-$ with atmospheric trace gases. *J Phys Chem*, 99(14):5001–8. doi:10.1021/j100014a021

Huey NA (1968). The lead dioxide estimation of sulfur dioxide pollution. *J Air Pollut Control Assoc*, 18(9):610–1. doi:10.1080/00022470.1968.10469176 PMID:5686386

Ingram WT, Golden J (1973). Smoke curve calibration. *J Air Pollut Control Assoc*, 3(2):110–5. doi:10.1080/00022470.1973.10469749

Jantunen M (1998). Assessing the benefits and costs of air pollution research: benzene exposure in the San Francisco Bay Area. *Atmos Environ*, 32(6):1135–6. doi:10.1016/S1352-2310(97)00354-3

Jayne JT, Leard DC, Zhang X, Davidovits P, Smith KA, Kolb CE et al. (2000). Development of an aerosol mass spectrometer for size and composition analysis of submicron particles. *Aerosol Sci Technol*, 33(1–2):49–70. doi:10.1080/027868200410840

Kanno S, Yanagisawa Y (1992). Passive ozone/oxidant sampler with coulometric determination using iodine/nylon-6 charge-transfer complex. *Environ Sci Technol*, 26(4):744–9. doi:10.1021/es00028a012

Käpylä M, Penttinen A (1981). An evaluation of the microscopical counting methods of the tape in Hirst-Burkard pollen and spore trap. *Grana*, 20(2):131–41. doi:10.1080/00173138109427653

Kasahara M (1999). Characterization of atmospheric aerosols and aerosol studies applying PIXE analysis. In: Spurny KR, editor. Analytical chemistry of aerosols. Boca Raton (FL): CRC Press; pp. 145–71.

Kaye P, Stanley WR, Hirst E, Foot EV, Baxter KL, Barrington SJ (2005). Single particle multichannel bio-aerosol fluorescence sensor. *Opt Express*, 13(10):3583–93. doi:10.1364/OPEX.13.003583 PMID:19495264

Kebabian PL, Herndon SC, Freedman A (2005). Detection of nitrogen dioxide by cavity attenuated phase shift spectroscopy. *Anal Chem*, 77(2):724–8. doi:10.1021/ac048715y PMID:15649079

Kelly TJ, Spicer CW, Ward GF (1990). An assessment of the luminol chemiluminescence technique for measurement of $NO_2$ in ambient air. *Atmos Environ*, 24A(9):2397–403. doi:10.1016/0960-1686(90)90332-H

Kirchstetter TW, Corrigan CE, Novakov T (2001). Laboratory and field investigation of the adsorption of gaseous organic compounds onto quartz filters. *Atmos Environ*, 35(9):1663–71. doi:10.1016/S1352-2310(00)00448-9

Kleindienst TE, Hudgens EE, Smith DF, McElroy FF, Bufalini JJ (1993). Comparison of chemiluminescence and ultraviolet ozone monitor responses in the presence of humidity and photochemical pollutants. *Air Waste*, 43(2):213–22. doi:10.1080/1073161X.1993.10467128 PMID:15739516

Kley D, McFarland M (1980). Chemiluminescence detector for NO and $NO_2$. *Atmos Technol*, 12:63–9.

Koutrakis P, Wolfson JM, Bunyaviroch A, Froehlich SE, Hirano K, Mulik JD (1993). Measurement of ambient ozone using a nitrite-coated filter. *Anal Chem*, 65(3):209–14. doi:10.1021/ac00051a004

Kreisberg NM, Hering SV, Williams BJ, Worton DR, Goldstein AH (2013). Quantification of hourly speciated organic compounds in atmospheric aerosols, measured by an in-situ thermal desorption aerosol gas chromatograph (TAG). *Aerosol Sci Technol*, 43(1):38–52. doi:10.1080/02786820802459583

Kring EV, Lautenberger WJ, Barry BW, Douglas JJ, Hoffman RA (1981). A new passive colorimetric air monitoring badge system for ammonia, sulfur dioxide and nitrogen dioxide. *AIHA J (Fairfax, Va)*, 42(5):373–81. doi:10.1080/15298668191419901

Krochmal D, Kalina A (1997). A method of nitrogen dioxide and sulphur dioxide determination in ambient air by use of passive samplers and ion chromatography. *Atmos Environ*, 31(20):3473–9. doi:10.1016/S1352-2310(97)00154-4

Lambe AT, Chacon-Madrid HJ, Nguyen NT, Weitkamp EA, Kreisberg NM, Hering SV et al. (2010). Organic aerosol speciation: intercomparison of thermal desorption aerosol GC/MS (TAG) and

filter-based techniques. *Aerosol Sci Technol*, 44(2):141–51. doi:10.1080/02786820903447206

Landsberger S, Creatchman M (1999). Elemental analysis of airborne particles. Newark (NJ): Gordon and Breach.

Larkin PJ (2011). IR and Raman spectroscopy: principles and spectral interpretation. Amsterdam, The Netherlands: Elsevier.

Lavanchy VMH, Gaggeler HW, Nyeki S, Baltensperger U (1999). Elemental carbon (EC) and black carbon (BC) measurements with a thermal method and an aethalometer at the high-alpine research station Jungfraujoch. *Atmos Environ*, 33(17):2759–69. doi:10.1016/S1352-2310(98)00328-8

Lee BU, Yun SH, Jung JH, Bae GN (2010). Effect of relative humidity and variation of particle number size distribution on the inactivation effectiveness of airborne silver nanoparticles against bacteria bioaerosols deposited on a filter. *J Aerosol Sci*, 41(5):447–56. doi:10.1016/j.jaerosci.2010.02.005

Lee K, Yanagisawa Y, Spengler JD, Billick IH (1992). Measurement of personal carbon monoxide exposures by mailed passive sampler. *J Air Waste Manage Assoc*, 42(9):1212–3. doi:10.1080/10473289.1992.10467070 PMID:1476711

Leith D, Sommerlatt D, Boundy MG (2007). Passive sampler for $PM_{10-2.5}$ aerosol. *J Air Waste Manag Assoc*, 57(3):332–6. doi:10.1080/10473289.2007.10465336 PMID:17385600

Levin JO, Andersson K, Lindahl R, Nilsson CA (1985). Determination of sub-part-per-million levels of formaldehyde in air using active or passive sampling on 2,4-dinitrophenylhydrazine-coated glass fiber filters and high-performance liquid chromatography. *Anal Chem*, 57(6):1032–5. doi:10.1021/ac00283a016

Levin JO, Lindahl R, Andersson K (1988). High-performance liquid-chromatographic determination of formaldehyde in air in the ppb to ppm range using diffusive sampling and hydrazone formation. *Environ Technol Lett*, 9(12):1423–30. doi:10.1080/09593338809384709

Li M, Chen H, Yang X, Chen J, Li C (2009). Direct quantification of organic acids in aerosols by desorption electrospray ionization mass spectrometry. *Atmos Environ*, 43(17):2717–20. doi:10.1016/j.atmosenv.2009.02.057

Li N, Sioutas C, Cho A, Schmitz D, Misra C, Sempf J et al. (2003). Ultrafine particulate pollutants induce oxidative stress and mitochondrial damage. *Environ Health Perspect*, 111(4):455–60. doi:10.1289/ehp.6000 PMID:12676598

Li YQ, Demerjian KL, Zahniser MS, Nelson DD, McManus JB, Herndon SC (2004). Measurement of formaldehyde, nitrogen dioxide, and sulfur dioxide at Whiteface Mountain using a dual tunable diode laser system. *J Geophys Res Atmos*, 109(D16):S08.1–S08.11.

Lin CJ, Pehkonen SO (1999). The chemistry of atmospheric mercury: a review. *Atmos Environ*, 33(13):2067–79. doi:10.1016/S1352-2310(98)00387-2

Lindsley WG, Blachere FM, Thewlis RE, Vishnu A, Davis KA, Cao G et al. (2010). Measurements of airborne influenza virus in aerosol particles from human coughs. *PLoS ONE*, 5(11):e15100 doi:10.1371/journal.pone.0015100 PMID:21152051

Lithgow GA, Robinson AL, Buckley SG (2004). Ambient measurements of metal-containing $PM_{2.5}$ in an urban environment using laser-induced breakdown spectroscopy. *Atmos Environ*, 38(20):3319–28. doi:10.1016/j.atmosenv.2004.03.017

Lodge JP (1989). Methods of air sampling and analysis. Chelsea (MI): Lewis Publishers.

Lodovici M, Venturini M, Marini E, Grechi D, Dolara P (2003). Polycyclic aromatic hydrocarbons air levels in Florence, Italy, and their correlation with other air pollutants. *Chemosphere*, 50(3):377–82. doi:10.1016/S0045-6535(02)00404-6 PMID:12656258

Lutter R, Wolz C (1997). Environmental policy analysis, peer reviewed: UV-B screening by tropospheric ozone: implications for the National Ambient Air Quality Standard. *Environ Sci Technol*, 31(3):142A–6A. doi:10.1021/es972180r

Maeda Y, Aoki K, Munemori M (1980). Chemiluminescence method for the determination of nitrogen dioxide. *Anal Chem*, 52(2):307–11. doi:10.1021/ac50052a022

Mari CM, Beghi M, Pizzini S, Faltemier J (1990). Electrochemical solid-state sensor for $SO_2$ determination in air. *Sens Actuators B Chem*, 2(1):51–5. doi:10.1016/0925-4005(90)80008-N

Marley NA, Gaffney JS, White RV, Rodriguez-Cuadra L, Herndon SE, Dunlea E et al. (2004). Fast gas chromatography with luminol chemiluminescence detection for the simultaneous determination of nitrogen dioxide and peroxyacetyl nitrate in the atmosphere. *Rev Sci Instrum*, 75(11):4595–605. doi:10.1063/1.1805271

Maron PA, Lejon DPH, Carvalho E, Bizet K, Lemanceau P, Ranjard L et al. (2005). Assessing genetic structure and diversity of airborne bacterial communities by DNA fingerprinting and 16S rDNA clone library. *Atmos Environ*, 39(20):3687–95. doi:10.1016/j.atmosenv.2005.03.002

Matsumoto J, Hirokawa J, Akimoto H, Kajii Y (2001). Direct measurement of $NO_2$ in the marine atmosphere by laser-induced fluorescence technique. *Atmos Environ*, 35(16):2803–14. doi:10.1016/S1352-2310(01)00078-4

Mazurenka MI, Fawcett BL, Elks JMF, Shallcross DE, Orr-Ewing AJ (2003). 410-nm diode laser cavity ring-down spectroscopy for trace detection of $NO_2$. *Chem Phys Lett*, 367(1–2):1–9. doi:10.1016/S0009-2614(02)01652-4

McConnaughey PW, McKee ES, Pritts IM (1985). Passive colorimetric dosimeter tubes for ammonia, carbon monoxide, carbon dioxide, hydrogen sulfide,

nitrogen dioxide and sulfur dioxide. *Am Ind Hyg Assoc J*, 46(7):357–62. doi:10.1080/15298668591394978 PMID:3939731

McMurry PH (2000b). The history of condensation nucleus counters. *Aerosol Sci Technol*, 33(4):297–322. doi:10.1080/02786820050121512

Menetrez MY, Foarde KK, Dean TR, Betancourt DA, Moore SA (2007). An evaluation of the protein mass of particulate matter. *Atmos Environ*, 41(37):8264–74. doi:10.1016/j.atmosenv.2007.06.021

Mielniczuk Z, Mielniczuk E, Larsson L (1993). Gas chromatography-mass spectrometry methods for analysis of 2- and 3-hydroxylated fatty acids: application for endotoxin measurement. *J Microbiol Methods*, 17(2):91–102. doi:10.1016/0167-7012(93)90002-Y

Miller JD, Young JC (1997). The use of ergosterol to measure exposure to fungal propagules in indoor air. *Am Ind Hyg Assoc J*, 58(1):39–43. doi:10.1080/15428119791013062 PMID:9018836

Mitrayana PT, Moeskops BWM, Persijn S et al. (2007). Diode-laser based photo-acoustic spectroscopy in atmospheric $NO_2$ detection. *Berkala Ilmiah MIPA*, 17:21–6.

Miyazaki Y, Kondo Y, Takegawa N, Komazaki Y, Fukuda M, Kawamura K et al. (2006). Time-resolved measurements of water-soluble organic carbon in Tokyo *Geophys Res: Atmos*, 111(D23): D23206. doi:10.1029/2006JD007125

Monn C (2001). Exposure assessment of air pollutants: a review on spatial heterogeneity and indoor/outdoor/personal exposure to suspended particulate matter, nitrogen dioxide and ozone. *Atmos Environ*, 35:1–32. doi:10.1016/S1352-2310(00)00330-7

Mulik GN, Kuchekar SR, Chavan MB (1986). Solvent extraction of zinc(II), indium(II), thallium(II) and bismuth(III) with *N*-*n*-octylaniline from hydrochloric acid media and their separation. *Indian J Chem A*, 25:1073–4.

Mulik J, Puckett R, Williams D, Sawicki E (1976). Ion chromatographic analysis of sulfate and nitrate in ambient aerosols. *Anal Lett*, 9(7):653–63. doi:10.1080/00032717608059128

Müller T, Henzing JS, de Leeuw G, Wiedensohler A, Alastuey A, Angelov H et al. (2011). Characterization and intercomparison of aerosol absorption photometers: result of two intercomparison workshops. *Atmos Meas Tech*, 4(2):245–58. doi:10.5194/amt-4-245-2011

Mullin JB, Riley JP (1955). The spectrophotometric determination of nitrate in natural waters, with particular reference to sea-water. *Anal Chim Acta*, 12:464–80. doi:10.1016/S0003-2670(00)87865-4

Mullins J, Emberlin J (1997). Sampling pollens. *J Aerosol Sci*, 28(3):365–70. doi:10.1016/S0021-8502(96)00439-9

Nehme B, Létourneau V, Forster RJ, Veillette M, Duchaine C (2008). Culture-independent approach of the bacterial bioaerosol diversity in the standard swine confinement buildings, and assessment of the seasonal effect. *Environ Microbiol*, 10(3):665–75. doi:10.1111/j.1462-2920.2007.01489.x PMID:18237302

Nielsen EM, Breum NO, Nielsen BH, Würtz H, Poulsen OM, Midtgaard U (1997). Bioaerosol exposure in waste collection: a comparative study on the significance of collection equipment, type of waste and seasonal variation. *Ann Occup Hyg*, 41(3):325–44. doi:10.1093/annhyg/41.3.325

NIOSH (1984). NIOSH manual of analytical methods. Cincinnati (OH): National Institute for Occupational Safety and Health.

NIOSH (1996). Method 5040 Issue 1 (Interim): Elemental carbon (diesel exhaust). In: NIOSH manual of analytical methods. 4th ed. Cincinnati (OH): National Institute for Occupational Safety and Health.

Noble CA, Prather KA (1996). Real-time measurement of correlated size and composition profiles of individual atmospheric aerosol particles. *Environ Sci Technol*, 30(9):2667–80. doi:10.1021/es950669j

Novakov T (1982). Soot in the atmosphere. In: Wolff GT, Klimisch RL, editors. Particulate carbon: atmospheric life cycle. New York: Plenum Press; pp. 19–41. doi:10.1007/978-1-4684-4154-3_2

Ockenden WA, Prest HF, Thomas GO, Sweetman A, Jones KC (1998). Passive air sampling of PCBs? Field calculation of atmospheric sampling rates by triolein-containing semipermeable membrane devices. *Environ Sci Technol*, 32(10):1538–43. doi:10.1021/es971020c

Ohtsuka T, Murakami T, Kaneko M, Sano S (1978). Measurement of degree of air pollution using triethanolamine filter papers - 2. Measurements of nitrogen dioxide, sulfur dioxide, and formaldehyde near city streets. *Kanagawa-ken Kogai Senta Nempo*, 10:169–70.

Orr DB, Hipfner JC, Chan WH, Lusis MA, Hunt JE (1967). The application of a passive permeation device for the measurement of ambient sulfur dioxide. *Atmos Environ (1967)*, 21(6):1473–5. doi:10.1016/0004-6981(67)90096-0

Orr FM Jr (2003). Sequestration via injection of carbon dioxide into the deep earth. In: The carbon dioxide dilemma - promising technologies and policies. Washington (DC): The National Academies Press; pp. 17–22.

Osthoff HD, Brown SS, Ryerson TB, Fortin TJ, Lerner BM, Williams EJ et al. (2006). Measurement of atmospheric $NO_2$ by pulsed cavity ring-down spectroscopy. *J Geophys Res Atmos*, 111(D12): D12305. doi:10.1029/2005JD006942

Palmes ED, Gunnison AF, DiMattio J, Tomczyk C (1976). Personal sampler for nitrogen dioxide. *Am Ind Hyg Assoc J*, 37(10):570–7. doi:10.1080/0002889768507522 PMID:983946

Park K, Chow JC, Watson JG, Trimble DL, Doraiswamy P, Park K et al. (2006). Comparison of continuous and filter-based carbon measurements at the Fresno

supersite. *J Air Waste Manag Assoc*, 56(4):474–91. doi:10.1080/10473289.2006.10464521 PMID:16681212

Park K, Dutcher D, Emery M, Pagels J, Sakurai H, Scheckman J et al. (2008). Tandem measurements of aerosol properties – a review of mobility techniques with extensions. *Aerosol Sci Technol*, 42(10):801–16. doi:10.1080/02786820802339561

Parrish DD (1990). Measurement problems of atmospheric nitrogen species. In: Abstracts of papers, part 1: 199th ACS National Meeting, Boston, Massachusetts, April 22–27, 1990. Abstract ANYL 182. Washington (DC): American Chemical Society.

Pashynska V, Vermeylen R, Vas G, Maenhaut W, Claeys M (2002). Development of a gas chromatographic/ion trap mass spectrometric method for the determination of levoglucosan and saccharidic compounds in atmospheric aerosols. Application to urban aerosols. *J Mass Spectrom*, 37(12):1249–57. doi:10.1002/jms.391 PMID:12489085

Peltier RE, Sullivan AP, Weber RJ, Brock CA, Wollny AG, Holloway JS et al. (2007). Fine aerosol bulk composition measured on WP-3D research aircraft in vicinity of the northeastern United States - results from NEAQS. *Atmos Chem Phys*, 7(12):3241–7. doi:10.5194/acp-7-3231-2007

Petzold A, Schloesser H, Sheridan PJ, Arnott WP, Ogren JA, Virkkula A (2005). Evaluation of multiangle absorption photometry for measuring aerosol light absorption. *Aerosol Sci Technol*, 39(1):40–51. doi:10.1080/027868290901945

Petzold A, Schönlinner M (2004). Multi-angle absorption photometry—a new method for the measurement of aerosol light absorption and atmospheric black carbon. *J Aerosol Sci*, 35(4):421–41. doi:10.1016/j.jaerosci.2003.09.005

Pierotti D (1990). Analysis of trace oxygenated hydrocarbons in the environment. *J Atmos Chem*, 10(4):373–82. doi:10.1007/BF00115780

Pisano JT, Drummond JW, Hastie DR (1996). A lightweight $NO_2$ instrument for vertical height profiles. *J Atmos Ocean Technol*, 13(2):400–6. doi:10.1175/1520-0426(1996)013<0400:ALNIFV>2.0.CO;2

Platt U, Perner D, Winer AM, Harris GW, Pitts JN Jr (1980). Detection of $NO_3$ in the polluted troposphere by differential optical absorption. *Geophys Res Lett*, 7(1):89–92. doi:10.1029/GL007i001p00089

Pozo K, Harner T, Shoeib M, Urrutia R, Barra R, Parra O et al. (2004). Passive-sampler derived air concentrations of persistent organic pollutants on a north-south transect in Chile. *Environ Sci Technol*, 38(24):6529–37. doi:10.1021/es049065i PMID:15669309

Pundt I, Mettendorf KU, Laepple T, Knab V, Xie P, Lösch J et al. (2005). Measurements of trace gas distributions using long-path DOAS-tomography during the motorway campaign BAB II: experimental setup and results for $NO_2$. *Atmos Environ*, 39(5):967–75. doi:10.1016/j.atmosenv.2004.07.035

Rantio-Lehtimäki A (1995). Aerobiology of pollen and pollen antigens. In: Cox CS, Wathes CM, editors. Bioaerosols handbook. Boca Raton (FL): Lewis Publishers; pp. 387–406.

Reiszner KD, West PW (1973). Collection and determination of sulfur dioxide incorporating permeation and West-Gaeke procedure. *Environ Sci Technol*, 7(6):526–32. doi:10.1021/es60078a001 PMID:22217283

Ridley BA, Howlett LC (1974). An instrument for nitric oxide measurements in the stratosphere. *Rev Sci Instrum*, 45(6):742–6. doi:10.1063/1.1686726 PMID:4839104

Rivett AC, Martin D, Nickless G, Simmonds PG, O'Doherty SJ, Gray DJ et al. (2003). In situ gas chromatographic measurements of halocarbons in an urban environment. *Atmos Environ*, 37(16):2221–35. doi:10.1016/S1352-2310(03)00148-1

Rogge WF, Mazurek MA, Hildemann LM, Cass GR, Simoneit BRT (1993). Quantification of urban organic aerosols at a molecular level: identification, abundance and seasonal variation. *Atmos Environ Part A Gen Topics*, 27(8):1309–30. doi:10.1016/0960-1686(93)90257-Y

Russell LM (2003). Aerosol organic-mass-to-organic-carbon ratio measurements. *Environ Sci Technol*, 37(13):2982–7. doi:10.1021/es026123w PMID:12875404

Rutter AP, Schauer JJ (2007). The impact of aerosol composition on the particle to gas partitioning of reactive mercury. *Environ Sci Technol*, 41(11):3934–9. doi:10.1021/es062439i PMID:17612171

Rylander R, Fogelmark B, McWilliam A, Currie A (1999). (1→3)-β-D-glucan may contribute to pollen sensitivity. *Clin Exp Immunol*, 115(3):383–4. doi:10.1046/j.1365-2249.1999.00829.x PMID:10193406

Saltzman BE (1954). Colorimetric microdetermination of nitrogen dioxide in atmosphere. *Anal Chem*, 26(12):1949–55. doi:10.1021/ac60096a025

Santiago EC, Cayetano MG (2007). Polycyclic aromatic hydrocarbons in ambient air in the Philippines derived from passive sampler with polyurethane foam disk. *Atmos Environ*, 41(19):4138–47. doi:10.1016/j.atmosenv.2007.01.021

Saraf A, Larsson L, Burge H, Milton D (1997). Quantification of ergosterol and 3-hydroxy fatty acids in settled house dust by gas chromatography-mass spectrometry: comparison with fungal culture and determination of endotoxin by a *Limulus* amebocyte lysate assay. *Appl Environ Microbiol*, 63(7):2554–9. PMID:9212406

Schaap M, Otjes RP, Weijers EP (2011). Illustrating the benefit of using hourly monitoring data on secondary inorganic aerosol and its precursors for model evaluation. *Atmos Chem Phys*, 11(21):11041–53. doi:10.5194/acp-11-11041-2011

Schauer JJ, Cass GR (2000). Source apportionment of wintertime gas-phase and particle-phase air pollutants using organic compounds as tracers. *Environ Sci Technol*, 34(9):1821–32. doi:10.1021/es981312t

Schauer JJ, Rogge WF, Hildemann LM, Mazurek MA, Cass GR, Simoneit BRT (1996). Source apportionment of airborne particulate matter using organic compounds as tracers. *Atmos Environ*, 30(22):3837–55. doi:10.1016/1352-2310(96)00085-4

Schiff HI, Mackay GI, Castledine C, Harris GW, Tran Q (1986). Atmospheric measurements of nitrogen dioxide with a sensitive luminol instrument. *Water Air Soil Pollut*, 30(1–2):105–14. doi:10.1007/BF00305179

Seethapathy S, Górecki T, Li X (2008). Passive sampling in environmental analysis. *J Chromatogr A*, 1184(1–2):234–53. doi:10.1016/j.chroma.2007.07.070 PMID:17719053

Shelton BG, Kirkland KH, Flanders WD, Morris GK (2002). Profiles of airborne fungi in buildings and outdoor environments in the United States. *Appl Environ Microbiol*, 68(4):1743–53. doi:10.1128/AEM.68.4.1743-1753.2002 PMID:11916692

Shields HC, Weschler CJ (1987). Analysis of ambient concentrations of organic vapors with a passive sampler. *JAPCA*, 37(9):1039–45. doi:10.1080/08940630.1987.10466301

Shoeib M, Harner T (2002). Characterization and comparison of three passive air samplers for persistent organic pollutants. *Environ Sci Technol*, 36(19):4142–51. doi:10.1021/es020635t PMID:12380087

Sigsby JE, Black FM, Bellar TA, Klosterman DL (1973). Chemiluminescent method for analysis of nitrogen compounds in mobile source emissions nitric oxide, nitrogen dioxide, and ammonia. *Environ Sci Technol*, 7(1):51–4. doi:10.1021/es60073a001

Sin DW, Wong YC, Sham WC, Wang D (2001). Development of an analytical technique and stability evaluation of 143 $C_3$-$C_{12}$ volatile organic compounds in Summa canisters by gas chromatography-mass spectrometry. *Analyst (Lond)*, 126(3):310–21. doi:10.1039/b008746g PMID:11284332

Slowik JG, Cross ES, Han JH, Davidovits P, Onasch TB, Jayne JT et al. (2007). An inter-comparison of instruments measuring black carbon content of soot particles. *Aerosol Sci Technol*, 41(3):295–314. doi:10.1080/02786820701197078

Sluis WW, Allaart MAF, Piters AJM, Gast LFL (2010). The development of a nitrogen dioxide sonde. *Atmos Meas Tech*, 3(6):1753–62. doi:10.5194/amt-3-1753-2010

Slusher DL, Huey LG, Tanner DJ, Flocke FM, Roberts JM (2004). A thermal dissociation–chemical ionization mass spectrometry (TD-CIMS) technique for the simultaneous measurement of peroxyacyl nitrates and dinitrogen pentoxide. *J Geophys Res Atmos*, 109(D19):D19315. doi:10.1029/2004JD004670

Small H (1978). An introduction to ion chromatography. In: Sawicki E, Mulik JD, Wittgenstein E, editors. Ion chromatographic analysis of environmental pollutants. Ann Arbor (MI): Ann Arbor Science Publishers; pp. 11–21.

Spencer MT, Shields LG, Prather KA (2007). Simultaneous measurement of the effective density and chemical composition of ambient aerosol particles. *Environ Sci Technol*, 41(4):1303–9. doi:10.1021/es061425+ PMID:17593734

Spicer CW, Kenny DV, Ward GF, Billick IH, Leslie NP (1994). Evaluation of $NO_2$ measurement methods for indoor air quality applications. *Air Waste*, 44(2):163–8. doi:10.1080/1073161X.1994.10467245

Steinbacher MZellweger C, Schwarzenbach B, Bugmann S, Buchmann B, Ordóñez C, Prevot ASH, Hueglin C (2007). Nitrogen oxide measurements at rural sites in Switzerland: bias of conventional measurement techniques. *J Geophys Res Atmos*, 112(D11):307.

Stolzenburg MR, Hering SV (2000). Method for the automated measurement of fine particle nitrate in the atmosphere. *Environ Sci Technol*, 34(5):907–14. doi:10.1021/es990956d

Sullivan AP, Peltier RE, Brock CA, de Gouw JA, Holloway JS, Warneke C et al. (2006). Airborne measurements of carbonaceous aerosol soluble in water over northeastern United States: method development and an investigation into water-soluble organic carbon sources. *J Geophys Res Atmos*, 111(D23):D23S46. doi:10.1029/2006JD007072

Sullivan AP, Weber RJ (2006). Chemical characterization of the ambient organic aerosol soluble in water: 1. Isolation of hydrophobic and hydrophilic fractions with a XAD-8 resin. *J Geophys Res Atmos*, 111(D5):D05314.

Takegawa N, Miyakawa T, Watanabe M, Kondo Y, Miyazaki Y, Han S et al. (2009). Performance of an Aerodyne aerosol mass spectrometer (AMS) during intensive campaigns in China in the summer of 2006. *Aerosol Sci Technol*, 43(3):189–204. doi:10.1080/02786820802582251

Tang H, Lau T (2000). A new all season passive sampling system for monitoring ozone in air. *Environ Monit Assess*, 65(1–2):129–37. doi:10.1023/A:1006497117066

Tang YS, Cape JN, Sutton MA (2001). Development and types of passive samplers for monitoring atmospheric $NO_2$ and $NH_3$ concentrations. *ScientificWorldJournal*, 1:513–29. doi:10.1100/tsw.2001.82 PMID:12805844

Tang YZ, Tran Q, Fellin P, Cheng WK, Drummond I (1993). Determination of $C_1$–$C_4$ hydrocarbons in air. *Anal Chem*, 65(14):1932–5. doi:10.1021/ac00062a021

Tanner RL (1993). Measuring the strong acid content of atmospheric aerosol particles. In: Newman L, editor. Measurement challenges in atmospheric chemistry. Washington (DC): American Chemical Society; pp. 229–41. http://dx.doi.org/10.1021/ba-1993-0232.ch008 doi:10.1021/ba-1993-0232.ch008

ten Brink H, Otjes R, Jongejan P, Slanina S (2007). An instrument for semi-continuous monitoring of the size-distribution of nitrate, ammonium, sulphate and chloride in aerosol. *Atmos Environ*, 41(13):2768–79. doi:10.1016/j.atmosenv.2006.11.041

Terzieva S, Donnelly J, Ulevicius V, Grinshpun SA, Willeke K, Stelma GN et al. (1996). Comparison of methods for detection and enumeration of airborne microorganisms collected by liquid impingement. *Appl Environ Microbiol*, 62(7):2264–72. PMID:8779564

Thomas RM, Trebs I, Otjes R, Jongejan PA, Ten Brink H, Phillips G et al. (2009). An automated analyzer to measure surface-atmosphere exchange fluxes of water soluble inorganic aerosol compounds and reactive trace gases. *Environ Sci Technol*, 43(5):1412–8. doi:10.1021/es8019403 PMID:19350912

Thornes J (1978). London's changing meteorology. In: Changing London. London: University Tutorial Press.

Thornton JA, Wooldridge PJ, Cohen RC (2000). Atmospheric $NO_2$: in situ laser-induced fluorescence detection at parts per trillion mixing ratios. *Anal Chem*, 72(3):528–39. doi:10.1021/ac9908905 PMID:10695138

Thornton JA, Wooldridge PJ, Cohen RC, Williams EJ, Hereid D, Fehsenfeld FC et al. (2003). Comparisons of in situ and long path measurements of $NO_2$ in urban plumes. *J Geophys Res Atmos*, 108(D16):4496. doi:10.1029/2003JD003559

Trebs I, Metzger S, Meixner FX, Helas G, Hoffer A, Rudich Y et al. (2005). The $NH_4^+$-$NO_3^-$-$Cl^-$-$SO_4^{2-}$-$H_2O$ aerosol system and its gas phase precursors at a pasture site in the Amazon Basin: how relevant are mineral cations and soluble organic acids? *J Geophys Res Atmos*, 110(D7):D07303. doi:10.1029/2004JD005478

Tripathi A, Tiwari PB, Mahima, Singh D (2009). Assessment of air pollution tolerance index of some trees in Moradabad city, India. *J Environ Biol*, 30(4):545–50. PMID:20120494

Tumolva L, Park JY, Kim J-S, Miller AL, Chow JC, Watson JG et al. (2010). Morphological and elemental classification of freshly emitted soot particles and atmospheric ultrafine particles using the TEM/EDS. *Aerosol Sci Technol*, 44(3):202–15. doi:10.1080/02786820903518907

Vairavamurthy A, Roberts JM, Newman L (1992). Methods for determination of low molecular weight carbonyl compounds in the atmosphere: a review. *Atmos Environ Part A Gen Topics*, 26(11):1965–93. doi:10.1016/0960-1686(92)90083-W

Vanhee LM, Nelis HJ, Coenye T (2008). Enumeration of airborne bacteria and fungi using solid phase cytometry. *J Microbiol Methods*, 72(1):12–9. doi:10.1016/j.mimet.2007.10.004 PMID:18054099

VDI (1996). Measurement of soot (immission) – Chemical analysis of elemental carbon by extraction and thermal desorption of organic carbon. VDI 2465 Part 1. Dusseldorf, Germany: Verein Deutscher Ingenieure.

VDI (1999). Measurement of soot (ambient air) – Thermographic determination of elemental carbon after thermal desorption of organic carbon. VDI 2465 Part 2. Dusseldorf, Germany: Verein Deutscher Ingenieure.

Veres P, Roberts JM, Warneke C, Welsh-Bon D, Zahniser M, Herndon S et al. (2008). Development of negative-ion proton-transfer chemical-ionization mass spectrometry (NI-PT-CIMS) for the measurement of gas-phase organic acids in the atmosphere. *Int J Mass Spectrom*, 274(1–3):48–55. doi:10.1016/j.ijms.2008.04.032

Villena G, Kleffmann J, Kurtenbach R, Wiesen P, Lissi E, Rubio MA et al. (2011). Vertical gradients of HONO, $NO_x$ and $O_3$ in Santiago de Chile. *Atmos Environ*, 45(23):3867–73. doi:10.1016/j.atmosenv.2011.01.073

Vinzents PS (1996). A passive personal dust monitor. *Ann Occup Hyg*, 40(3):261–80. doi:10.1093/annhyg/40.3.261

Wagner J, Leith D (2001a). Passive aerosol sampler. Part I: principle of operation. *Aerosol Sci Technol*, 34(2):186–92. doi:10.1080/027868201300034808

Wagner J, Leith D (2001b). Passive aerosol sampler. Part II: wind tunnel experiments. *Aerosol Sci Technol*, 34(2):193–201. doi:10.1080/027868201300034826

Wagner J, Leith D (2001c). Field tests of a passive aerosol sampler. *J Aerosol Sci*, 32(1):33–48. doi:10.1016/S0021-8502(00)00055-0

Wang X, Caldow R, Sem GJ, Hama N, Sakurai H (2010b). Evaluation of a condensation particle counter for vehicle emission measurement: experimental procedure and effects of calibration aerosol material. *J Aerosol Sci*, 41(3):306–18. doi:10.1016/j.jaerosci.2010.01.001

Wang XL, Chancellor G, Evenstad J, Farnsworth JE, Hase A, Olson GM et al. (2009). A novel optical instrument for estimating size segregated aerosol mass concentration in real time. *Aerosol Sci Technol*, 43(9):939–50. doi:10.1080/02786820903045141

Ward T, Smith T (2004). High-volume PUF versus low-volume PUF sampling comparison for collecting gas plus particulate polycyclic aromatic hydrocarbons. *Aerosol Sci Technol*, 38(10):972–9. doi:10.1080/027868290516790

Watson JG, Chow JC (1984). Particle and gas measurements on filters. In: Markert B, editor. Environmental sampling for trace analysis. New York: VCH; pp. 125–61.

Watson JG, Chow JC (2013). Source apportionment. In: El-Shaarwi AH, Piegorsch WW, editors. Encyclopedia of environmetrics. Chichester, UK: John Wiley & Sons, Ltd. doi:10.1002/9780470057339.vas034.pub2

Watson JG, Chow JC, Chen L-WA (2005). Summary of organic and elemental carbon/black carbon analysis methods and intercomparisons. *AAQR*, 5:65–102.

Watson JG, Chow JC, Frazier CA (1999). X-ray fluorescence analysis of ambient air samples. In: Landsberger S, Creatchman M, editors. Elemental analysis of airborne

particles. Amsterdam, The Netherlands: Gordon and Breach Science; pp. 67–96.

Weatherburn MW (1967). Phenol-hypochlorite reaction for determination of ammonia. *Anal Chem*, 39(8):971–4. doi:10.1021/ac60252a045

Weber R, Orsini D, Duan Y, Baumann K, Kiang CS, Chameides W et al. (2003). Intercomparison of near real time monitors of $PM_{2.5}$ nitrate and sulfate at the U.S. Environmental Protection Agency Atlanta Supersite. *J Geophys Res Atmos*, 108(D7):8421. doi:10.1029/2001JD001220

Welthagen W, Schnelle-Kreis J, Zimmermann R (2003). Search criteria and rules for comprehensive two-dimensional gas chromatography-time-of-flight mass spectrometry analysis of airborne particulate matter. *J Chromatogr A*, 1019(1):(2):233–49. doi:10.1016/j.chroma.2003.08.053 PMID:14650618

Wendel GJ, Stedman DH, Cantrell CA, Damrauer L (1983). Luminol-based nitrogen dioxide detector. *Anal Chem*, 55(6):937–40. doi:10.1021/ac00257a027

Werner H (1989). Die Ozonkerze - ein Passiver Integrator Zurflachendeckenden Abschatzung der Ozonimmission. In: Proceedings of the 14th International Meeting for Specialists in Air Pollution Effects on Forest Ecosystems, Interlaken, Switzerland, 2–8 October 1988. Birmensdorf, Switzerland: Eidgenössische Anstalt für das forstliche Versuchswesen; pp. 547–9.

Weschler CJ, Shields HC, Rainer D (1990). Concentrations of volatile organic compounds at a building with health and comfort complaints. *Am Ind Hyg Assoc J*, 51(5):261–8. doi:10.1080/15298669091369628 PMID:2346114

Willems JJH (1993). Low-cost methods for measuring air pollutants (a training program). Report R-635. Wageningen, The Netherlands: Wagenigen (NI) Agricultural University, Department of Air Quality.

William BJ, Goldstein AH, Kreisberg NM, Hering SV (2006). An in-situ instrument for speciated organic composition of atmospheric aerosols: thermal desorption aerosol GC/MS-FID (TAG). *Aerosol Sci Technol*, 40(8):627–38. doi:10.1080/02786820600754631

Winterhalter R, Kippenberger M, Williams J, Fries E, Sieg K, Moortgat GK (2009). Concentrations of higher dicarboxylic acids $C_5$–$C_{13}$ in fresh snow samples collected at the high alpine research station Jungfraujoch during CLACE 5 and 6. *Atmos Chem Phys*, 9(6):2097–112. doi:10.5194/acp-9-2097-2009

Witt MLI, Meheran N, Mather TA, de Hoog JCM, Pyle DM (2010). Aerosol trace metals, particle morphology and total gaseous mercury in the atmosphere of Oxford, UK. *Atmos Environ*, 44(12):1524–38. doi:10.1016/j.atmosenv.2010.01.008

Wittig AE, Takahama S, Khlystov AY, Pandis SN, Hering S, Kirby B et al. (2004). Semi-continuous $PM_{2.5}$ inorganic composition measurements during the Pittsburgh Air Quality Study. *Atmos Environ*, 38(20):3201–13. doi:10.1016/j.atmosenv.2004.03.002

Yang M, Howell SG, Zhuang J, Huebert BJ (2009). Attribution of aerosol light absorption to black carbon, brown carbon, and dust in China – interpretations of atmospheric measurements during EAST-AIRE. *Atmos Chem Phys*, 9(6):2035–50. doi:10.5194/acp-9-2035-2009

Yao X, Shairsingh K, Lam PH, Evans GJ (2009). Underestimation of sulfate concentration in $PM_{2.5}$ using a semi-continuous particle instrument based on ion chromatography. *J Environ Monit*, 11(6):1292–7. doi:10.1039/b819630c PMID:19513462

Yatavelli RLN, Thornton JA (2010). Particulate organic matter detection using a micro-orifice volatilization impactor coupled to a chemical ionization mass spectrometer (MOVI-CIMS). *Aerosol Sci Technol*, 44(1):61–74. doi:10.1080/02786820903380233

Zielinska B, Arey JB, Atkinson R (1990). The atmospheric formation of nitroarenes and their occurrence in ambient air. In: Howard PC, Hecht SS, Beland FA, editors. Nitroarenes: occurrence, metabolism, and biological impact. Proceedings of the Fourth International Conference on N-Substituted Aryl Compounds: Occurrence, Metabolism and Biological Impact of Nitroarenes, held July 15–19, 1989, in Cleveland, Ohio. New York (NY): Plenum Press; pp. 73–84.

Zielinska B, Fung KK (1992). Composition and concentrations of semi-volatile hydrocarbons. DRI document 8202.FR1. Sacramento (CA): Desert Research Institute, Reno, NV, for California Air Resources Board.