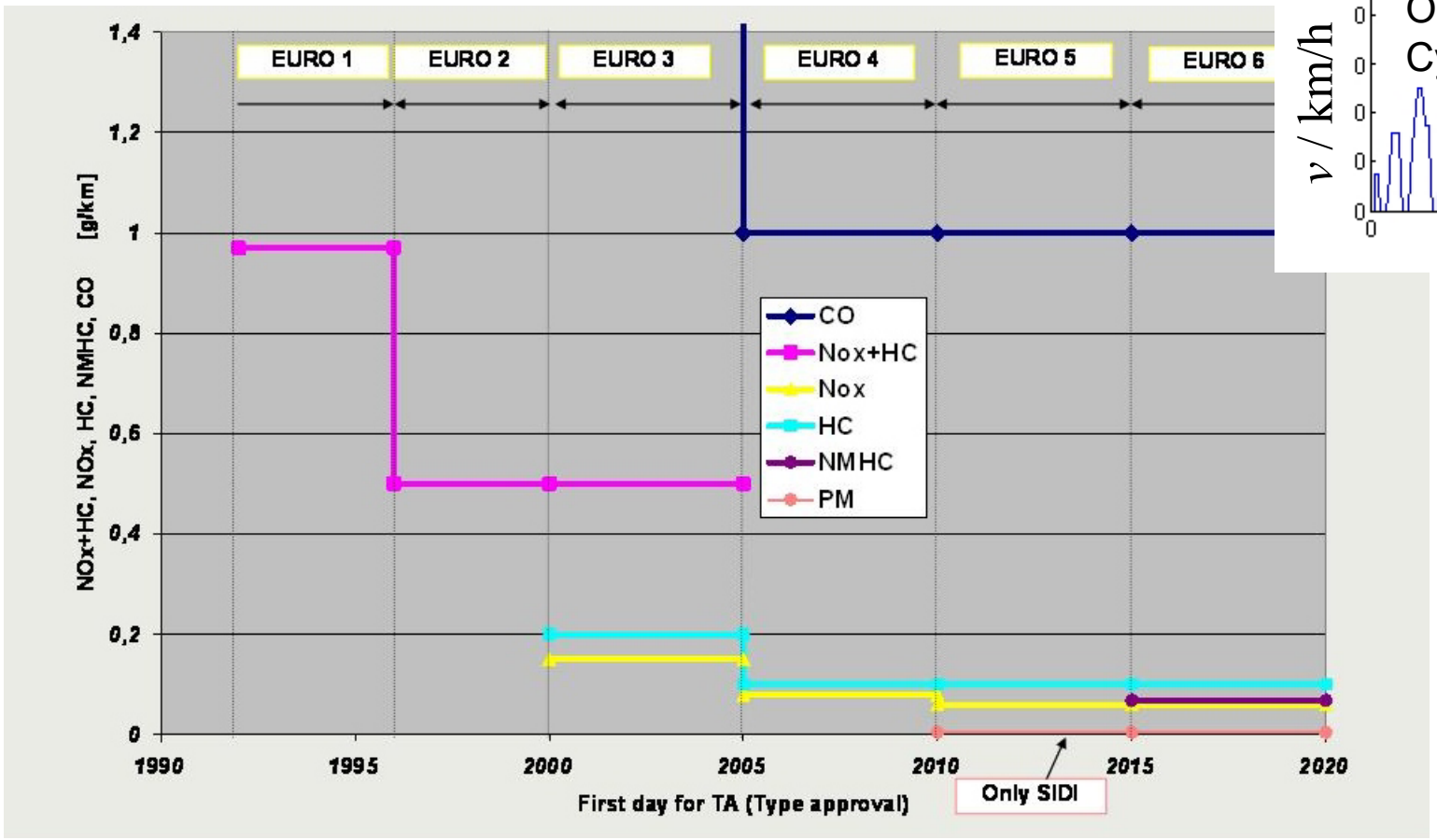
5.1 Speed, Forces and Torque

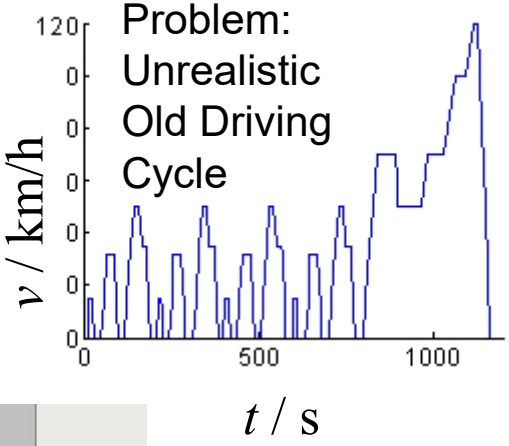
5.2 Exhaust Gas Analysis

5.3 Flows, Pressures and Temperatures

5.4 Optical Methods

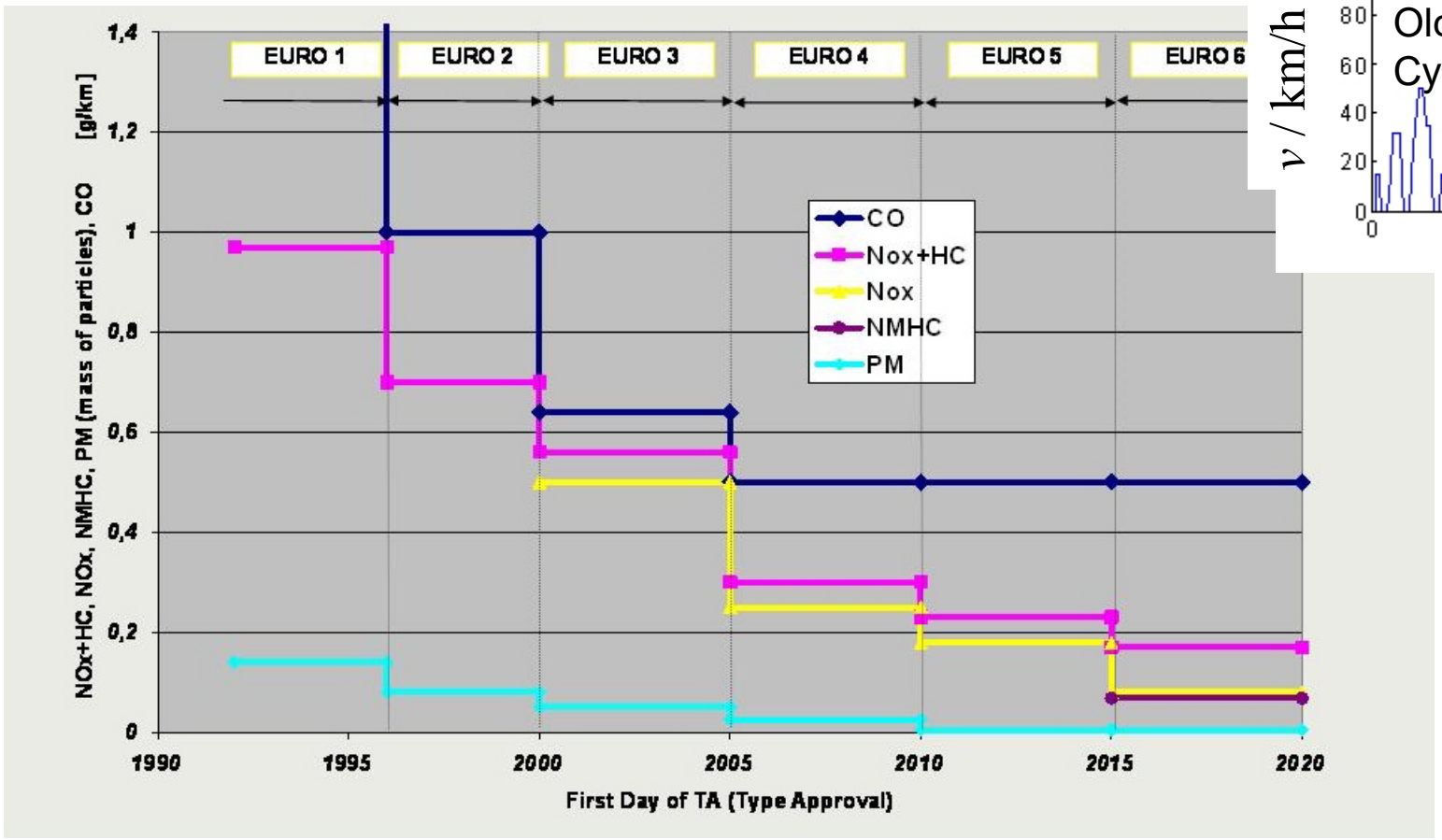
Legal Requirements for Gasoline Passenger Cars

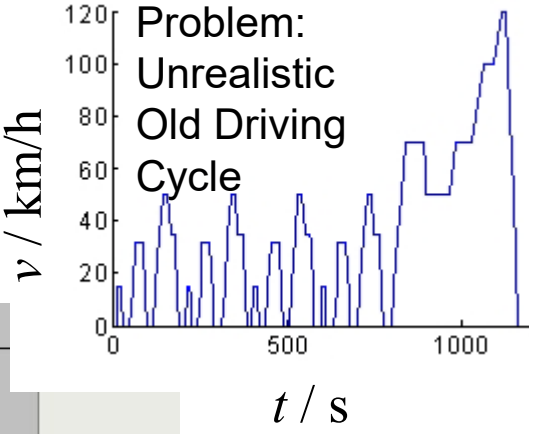




Source:
Wikimedia

Legal Requirements for Diesel Passenger Cars





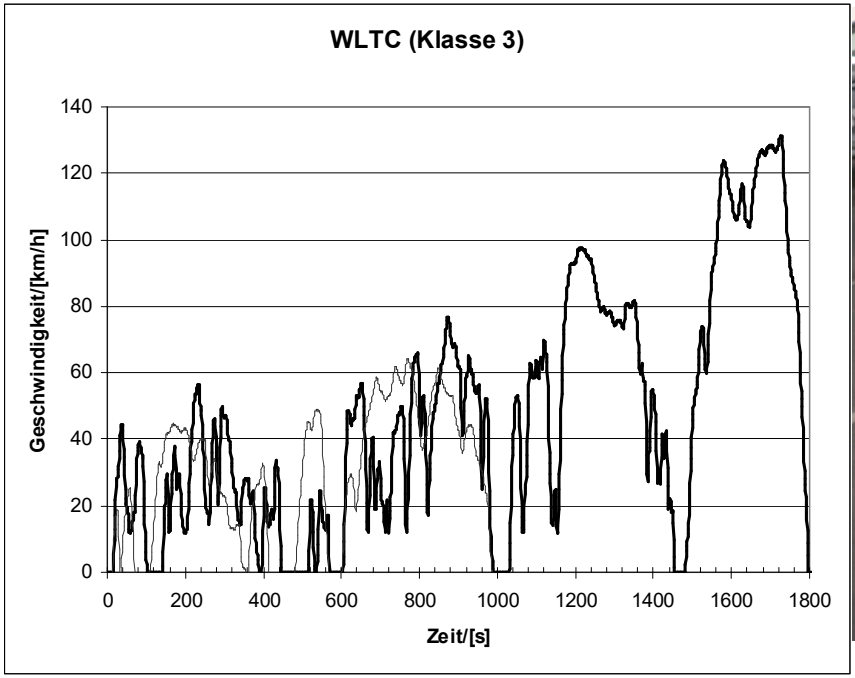
Source:
Wikimedia

Measurement Systems
Exhaust Gas Analysis

WLTP (Worldwide Harmonized Light-Duty Vehicles Test Procedure) incl. WLTC

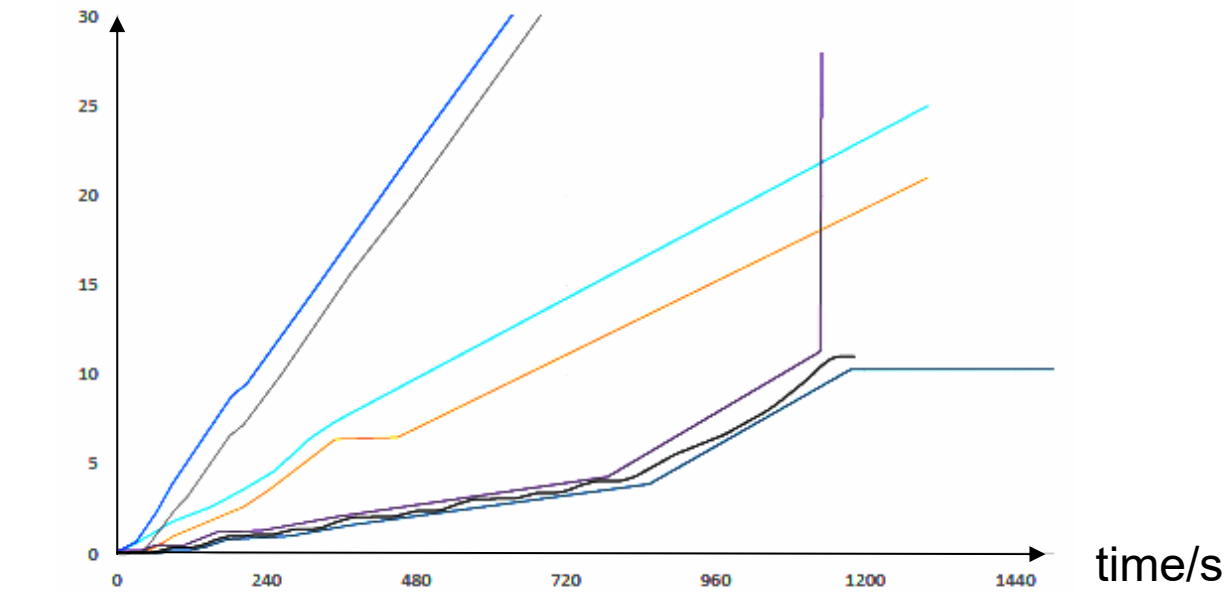
+

RDE (Real Driving Emissions)

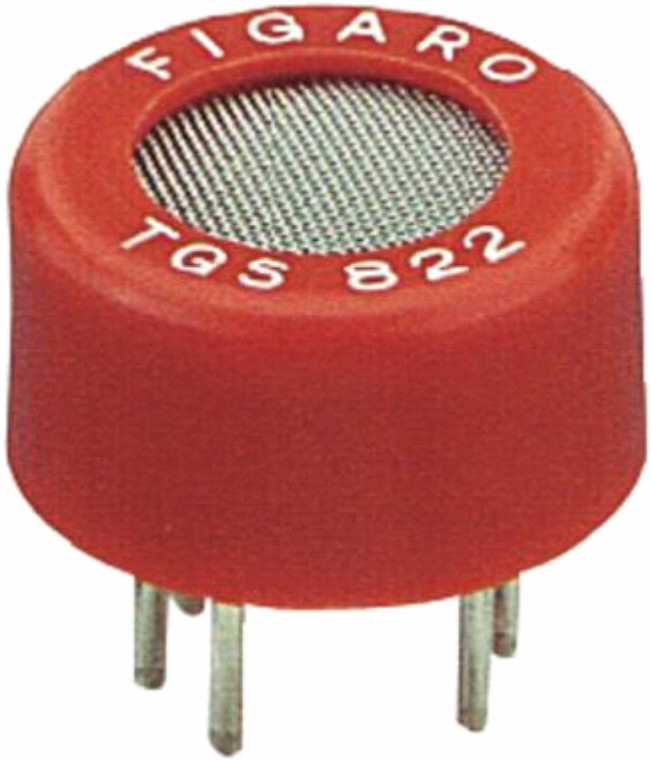


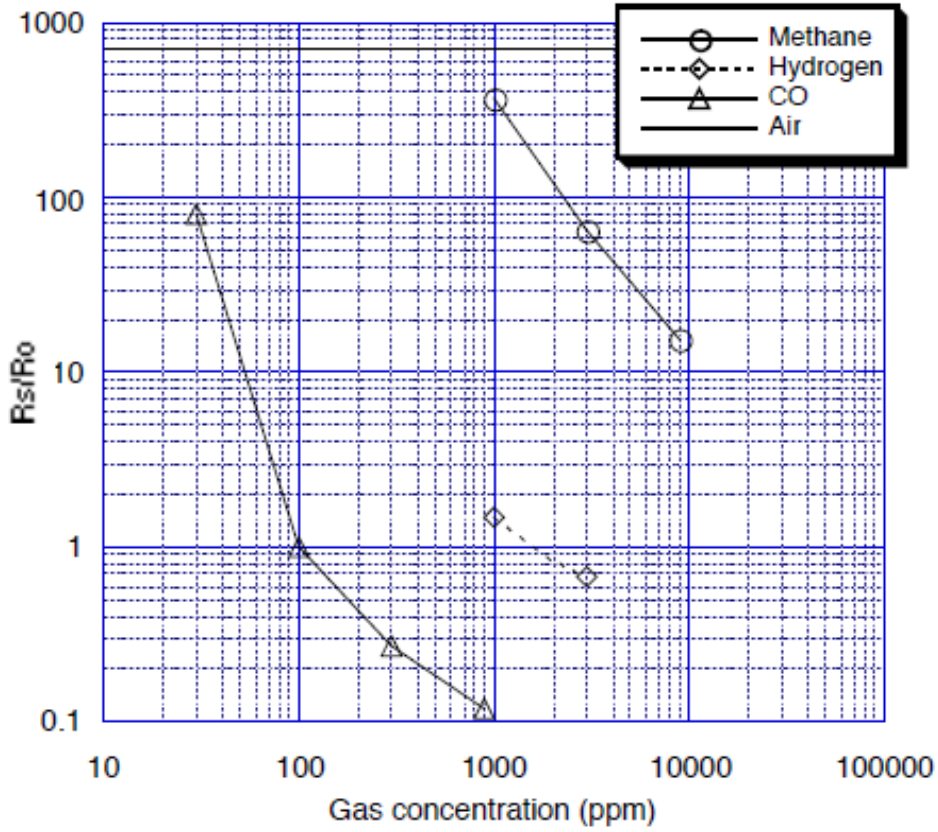
Source:
K. Borgeest, Manipulation von Abgaswerten, Springer-Vieweg, 2023

Defeat Device VW EA189



Cheapest Solution, due to lack of accuracy not typically used in test cells:
Semiconductor Sensor (Metal Oxide)





Source: Figaro

Cheap Solution (due to lack of accuracy not typically used in test cells):
Service Tester

German “Abgasuntersuchung”:

Diesel	Gasoline
Visual Inspection	Visual Inspection
(Engine Temperature)	(Engine Temperature)
Idle Speed	Idle Speed
Opacity	CO
	Lambda
	Ignition
On Board Diagnosis	On Board Diagnosis

Typical Test
Bench System

(here: 2 Lines)

Monitor/
Industry PC

Analyzers for Certain
Gases/Concentrations

Gas Processing Unit

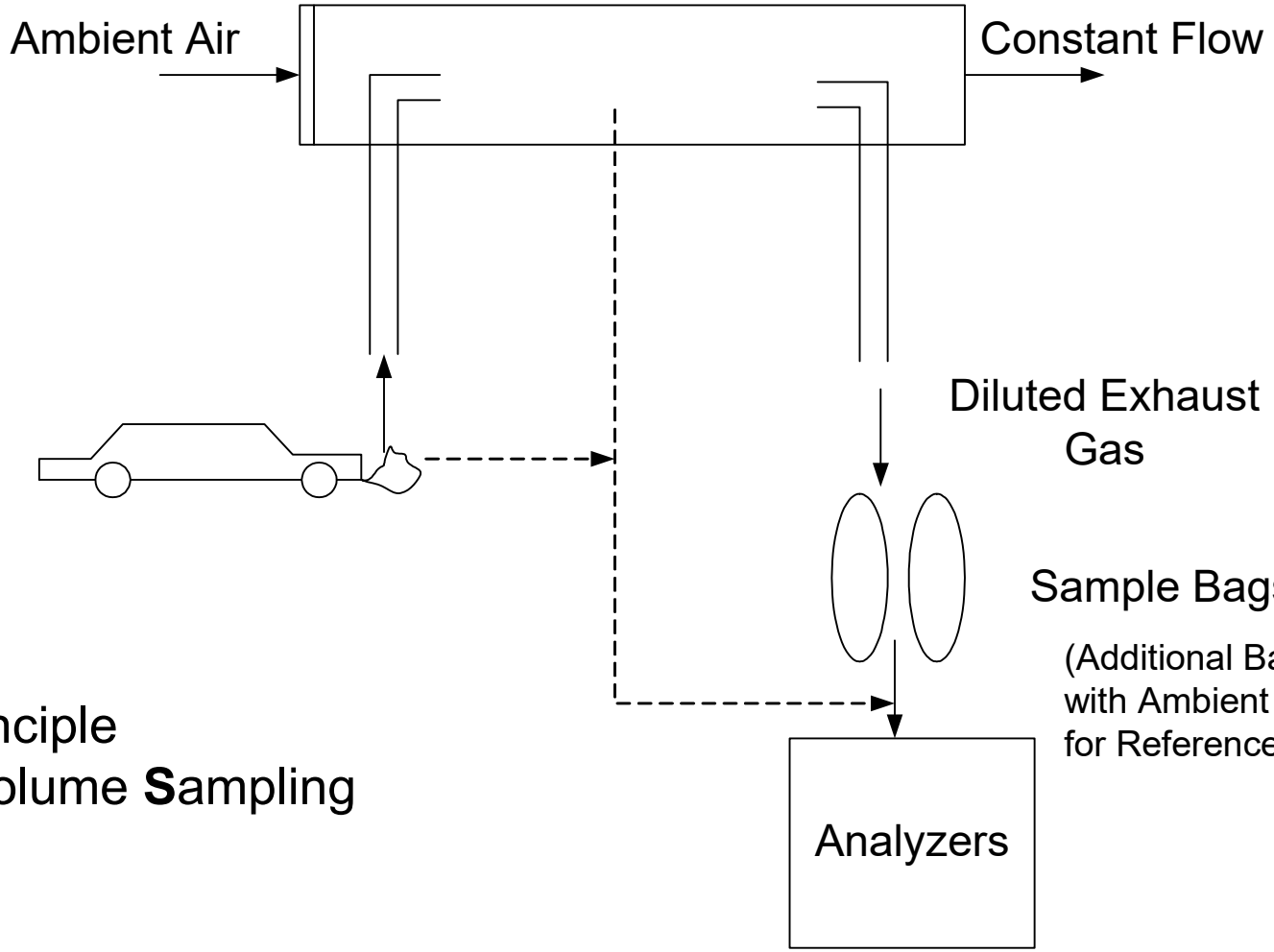
Source: AVL

Development Passenger Cars: Engine and Vehicle Test Bench

Development Trucks: Engine Test Bench

Type Approval Passenger Cars: Vehicle Test Bench,
Dilution and Bag Collection, from 09/2017 Real Driving Emissions (RDE)

Type Approval Trucks: Engine Test Bench,
Dilution and Bag Collection, Real Driving Emissions



Dilution Principle
Constant **V**olume **S**ampling

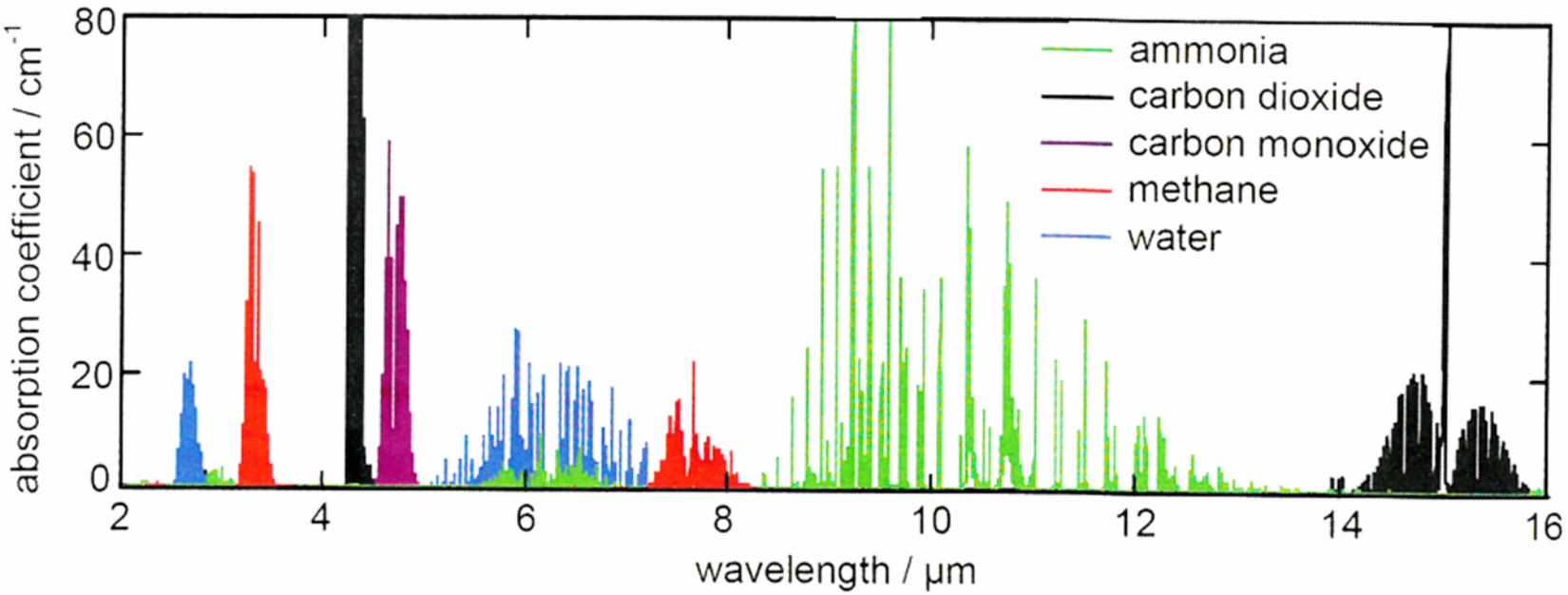
Common Requirements to Analyzers

- Accuracy
- Speed
- Low Maintenance

Carbon Monoxide

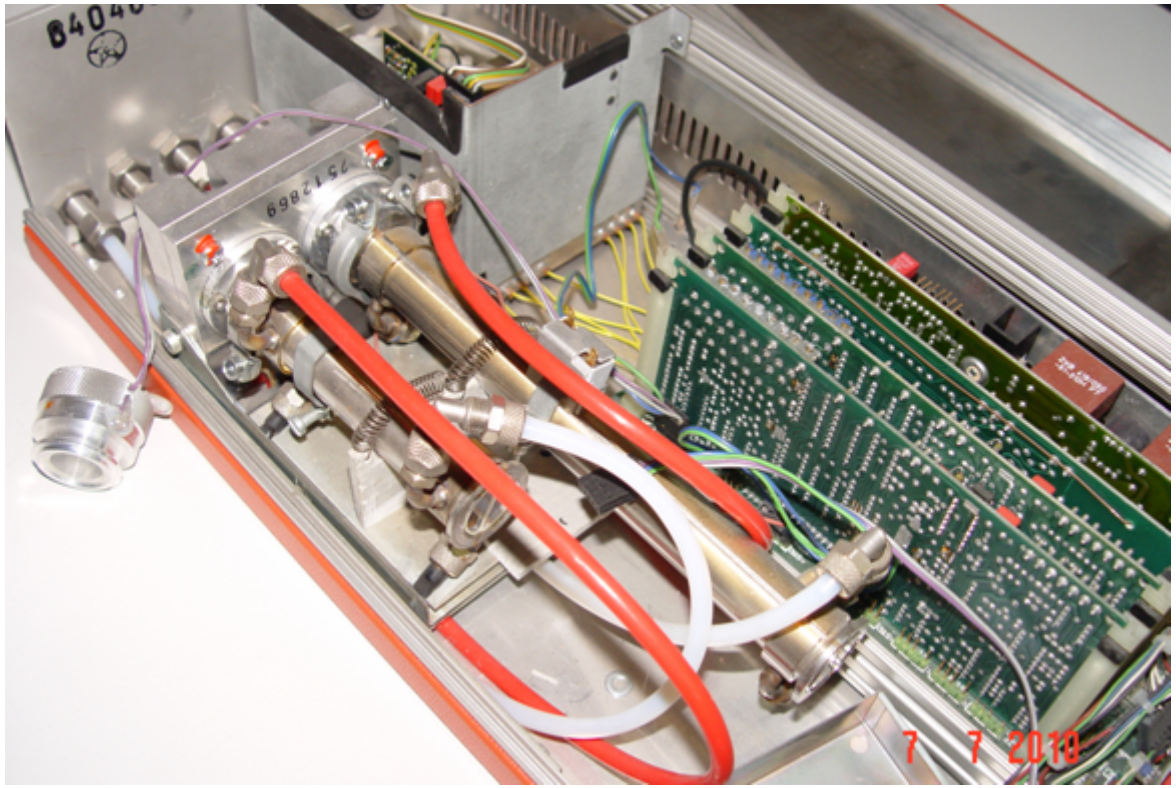
- Impairs Oxygen Transport Capacity of Blood
- Sources: Engines, Stoves, Cigarettes, ...
- Measured for „Abgasuntersuchung“, Type Approval or Development
- Oxidable, Infrared Absorbing

Standard Solution CO, CO_2: NDIR (Non Dispersive Infrared Spectroscopy)



Source: Hodgkinson, Tatam, Meas. Sci. Technol. 24 (2013)

Standard Solution CO, CO_2: NDIR (Non Dispersive Infrared Spectroscopy)



Carbon Dioxide

- Greenhouse Gas
- Sources: Combustion, Animals, Vulcanos, ...
- Total CO_2 can be calculated from Fuel Consumption
- Measured e.g. for Exhaust Gas Recirculation Testing/Development
- Infrared Absorbing → Measurement like CO

Hydrocarbons

Methane
+
NMHC (Non Methane Hydrocarbons)

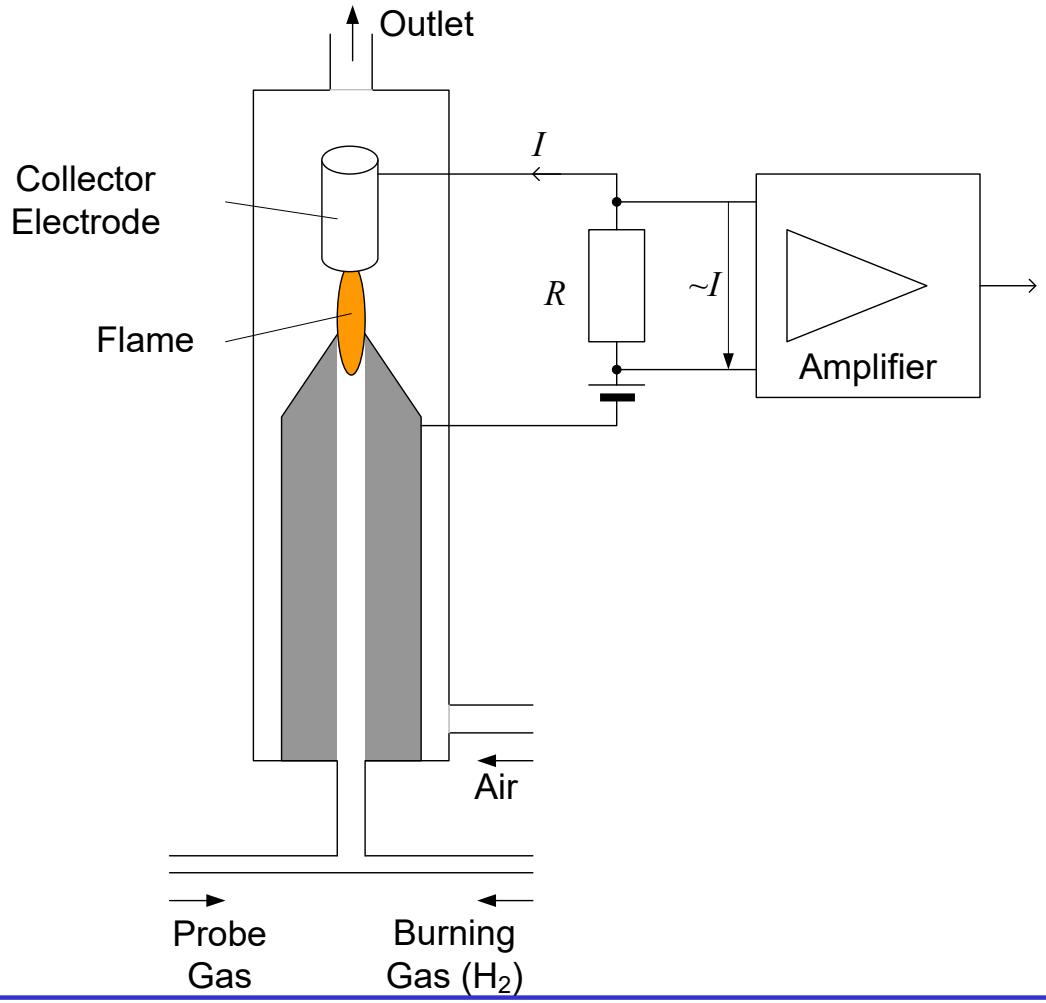
} THC
(Total Hydrocarbons)

- Slightly Toxic, some are Carcinogenic

- Sources: Incompletely Burnt Fuel or Lubricant
  (**mainly 2 Stroke Engines**), Evaporation

- Oxidable, Infrared Absorbing

Standard Solution HC: FID (Flame Ionization Detector)



FID (Flame Ionization Detector)

$$CH + O \rightarrow CHO^{+} + e^{-} .$$

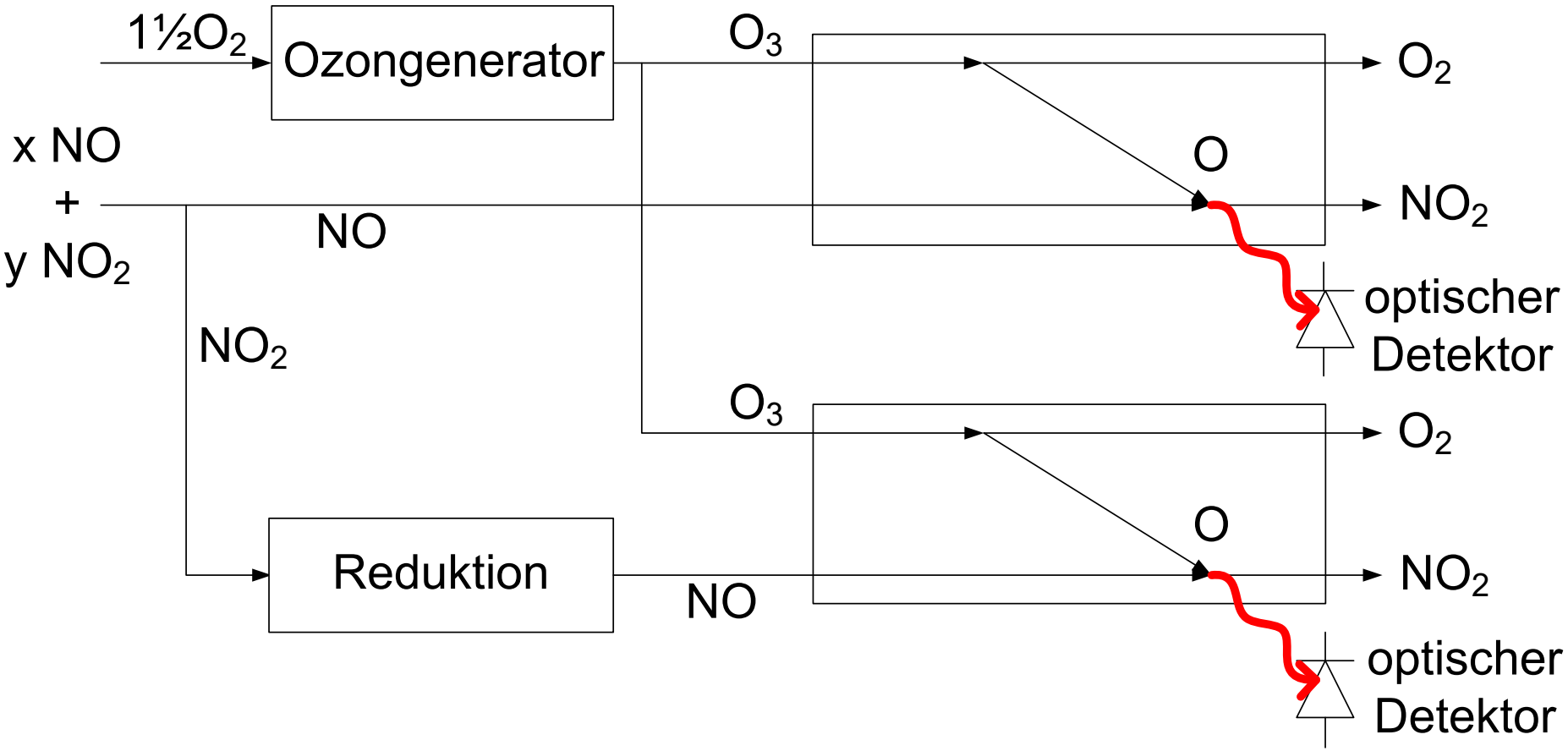
FID works as a “Carbon Counter”

	C-Atoms per Molecules	Example of Ion Count Mean Value
Methane	1	1,0
Ethane	2	2,0
Propane	3	3,0
n-Butane	4	3,8
i-Butane	4	3,8
Benzene	6	5,8

Nitrogen Oxides

- Irritate Respiratory Organs, Catalysis of Ozone Formation in Summer
- Sources: High Combustion Peak Temperatures,
  in Particular of Diesel and FSI Engines
- Measured e.g. for Type Approval and in Development
- Chemiluminescent Oxidation, UV Absorption

Standard Solution NO_X: CLD (Chemiluminescence Detector)



Standard Solution NO_x: CLD (Chemiluminescence Detector)

New Solution: QCL (Quantum Cascade Laser Spectroscopy)

Oxygen

- not Harmful
- Sources: everywhere
- Remaining Oxygen could hint to Incomplete Combustion
- Paramagnetic ($\mu_r = 1$ **+ 0,4·10^{-6}**)

Standard Solution O_2: by Paramagnetism: Magnetomechanic Principle

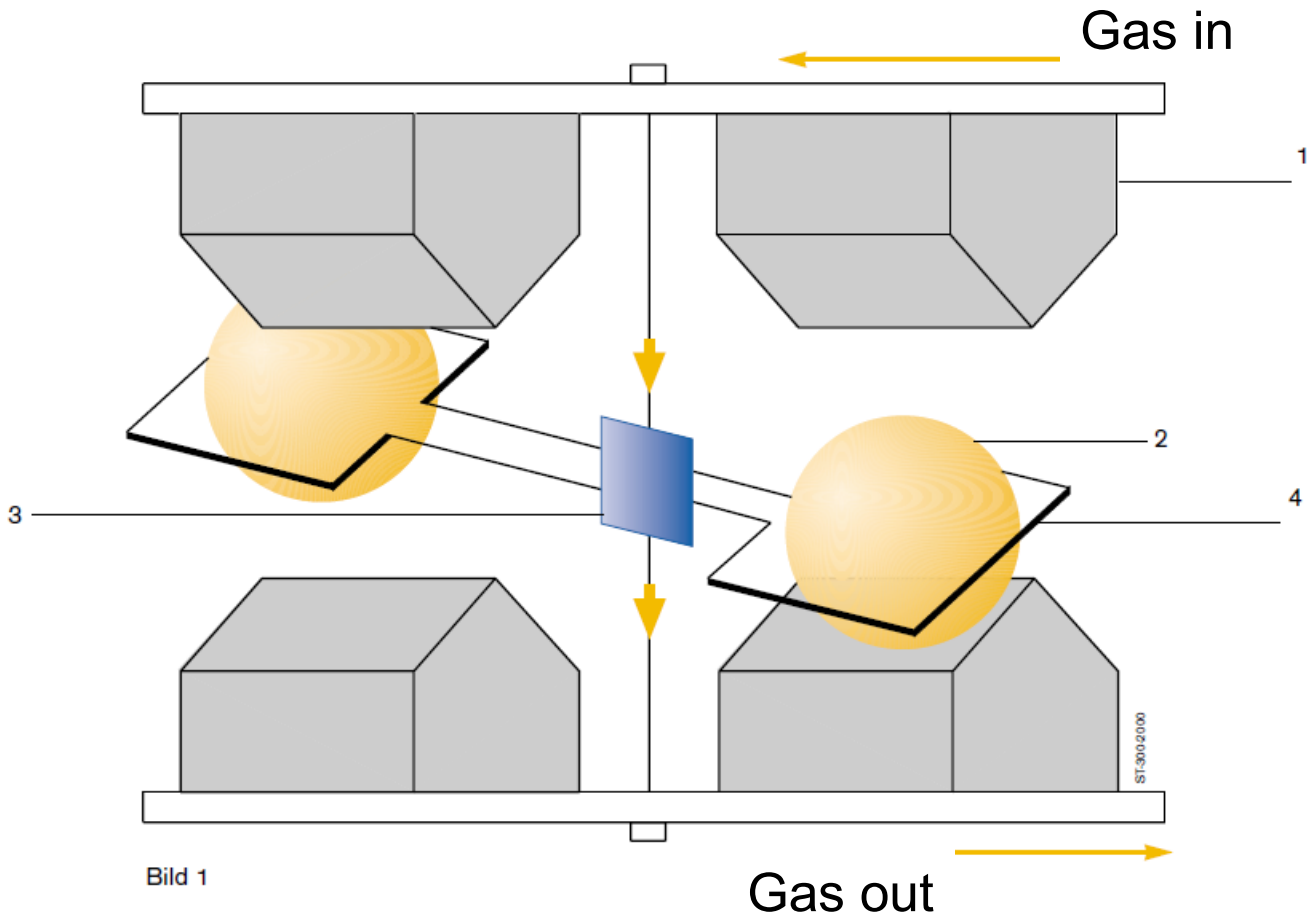
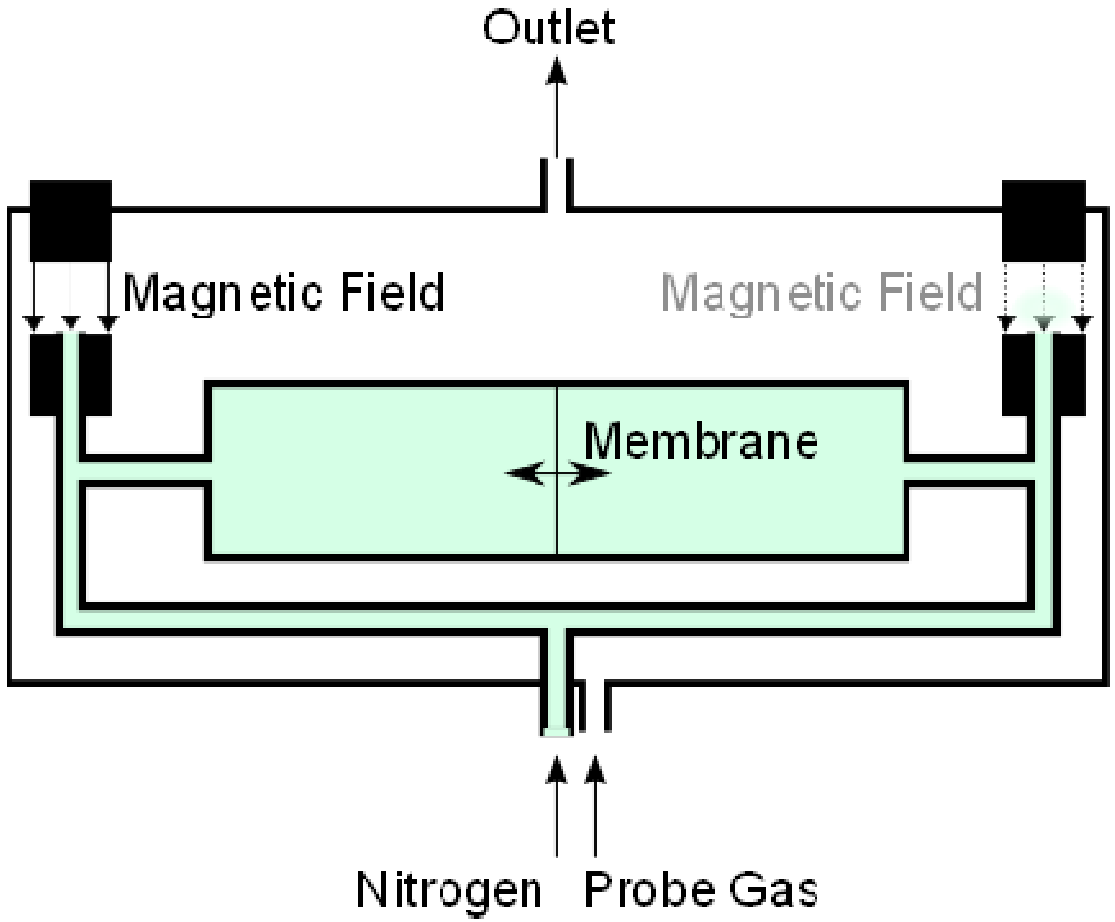


Bild 1

1 Magnets
2 Balls with N_2-Filling
3 Indicator
4 „Dumbbell“

Source: Dräger, Lübeck

Standard Solution O_2: by Paramagnetism: Magnetopneumatic Principle



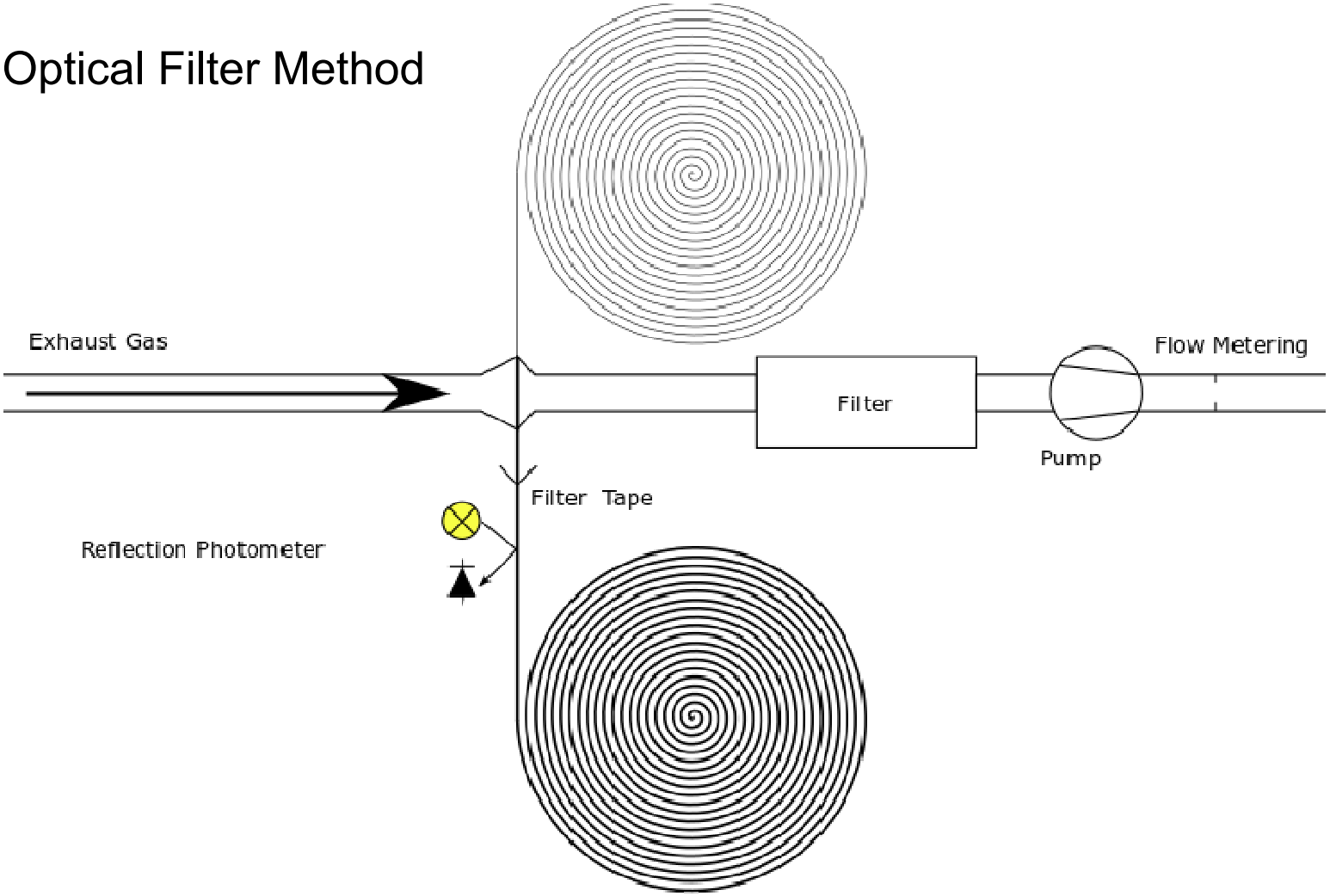
Particulate Matter

- Cancerogen
- Sources: Engines, Stoves, Cigarettes
- Carbon with Polycyclic Aromatic Hydrocarbons on Surface
- Measured for type Approval and Development
- Several Physical Effects for Measurement

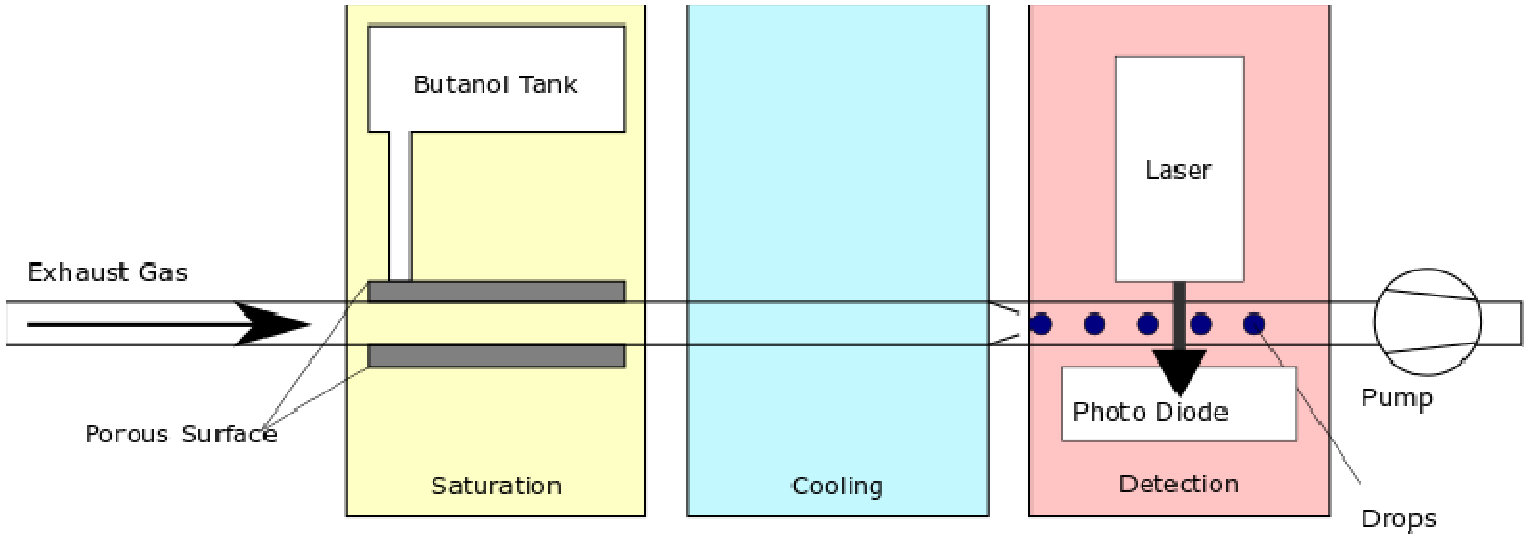
Particulate Measurement

- Opacity
- Filter (Optical Analysis)
- Filter (Gravimetric Analysis)
- Photoacoustic
- Condensation Particle Counter (CPC), yields Number of Particles

Optical Filter Method

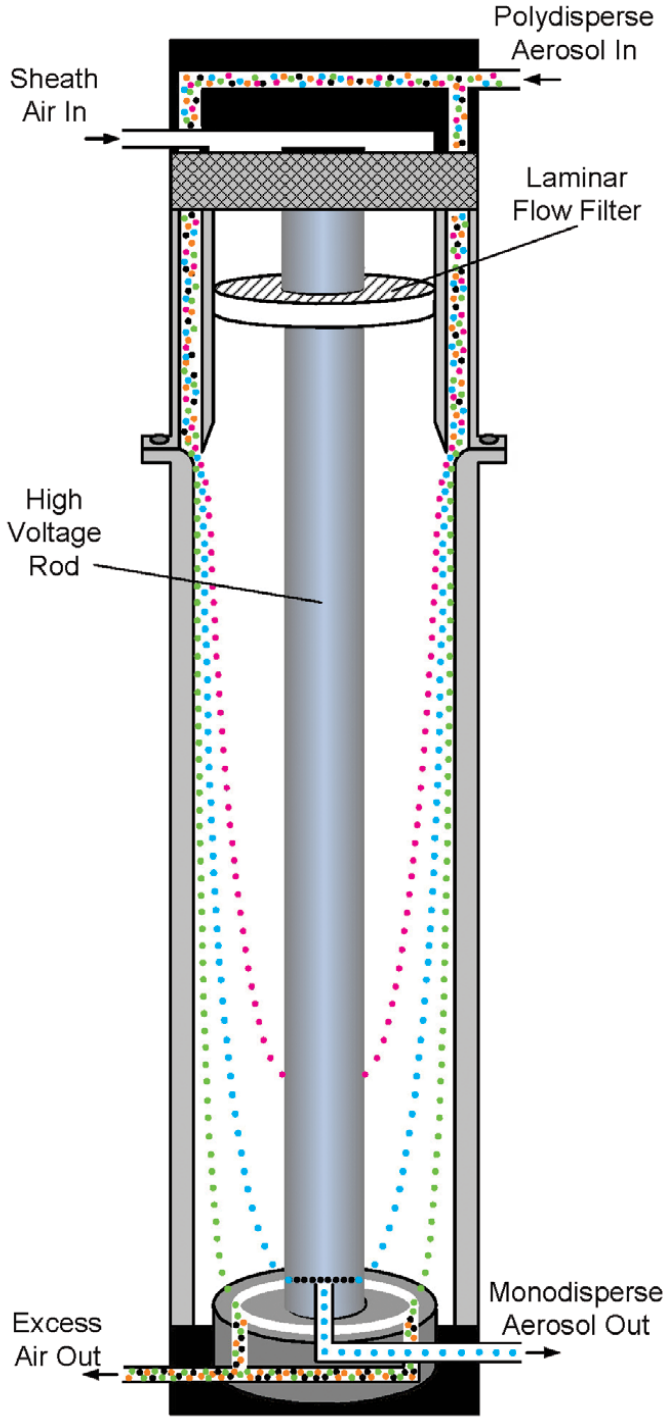


Condensation Particle Counter



Distinction of Particle Size

Source:
TSI

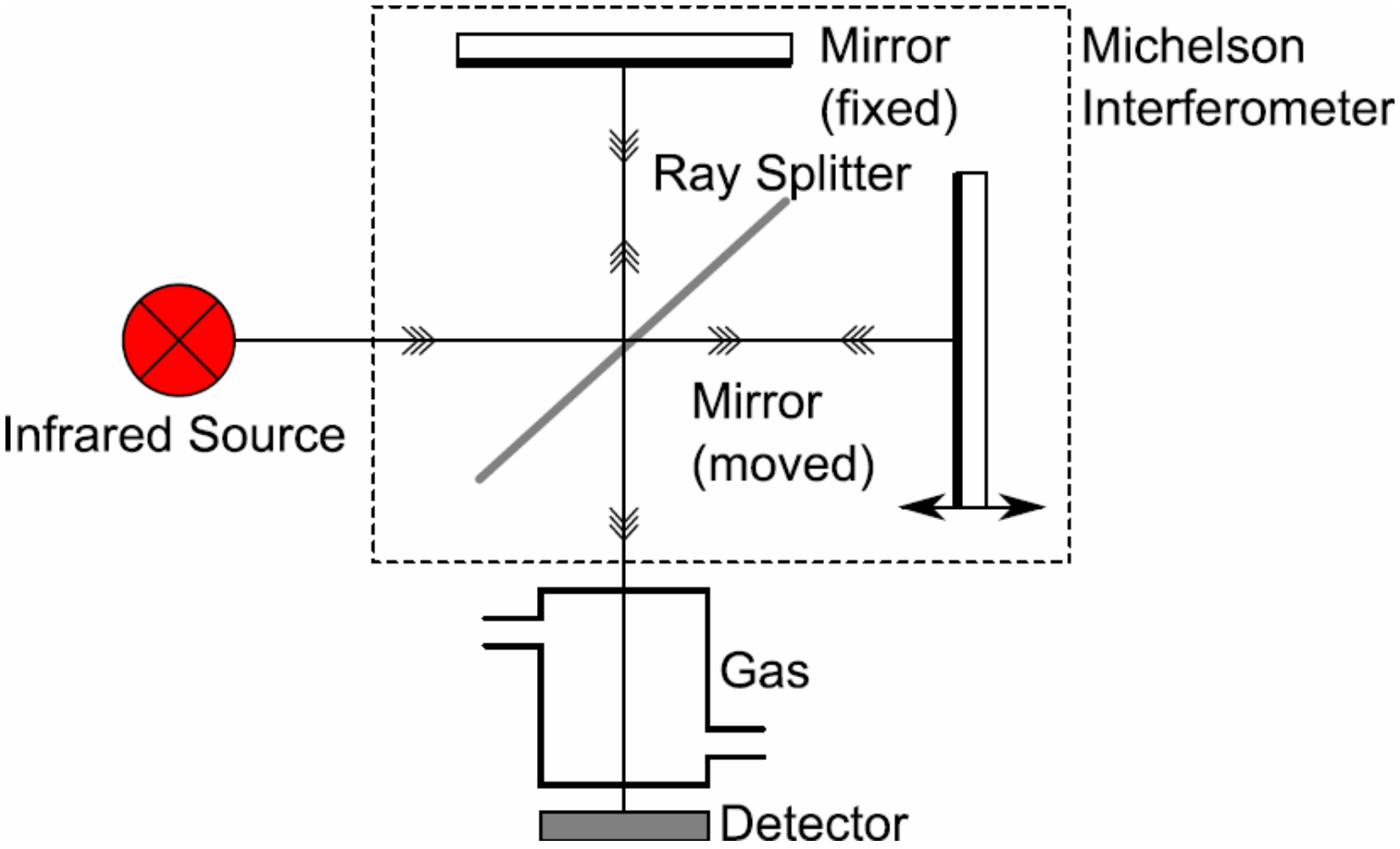


Universal Analyzers for Multiple Gases

- Fourier Transform Infrared Spectroscopy (FTIR)
  - not much more expensive than set of single analyzers
  - analyzes many gases, but not all

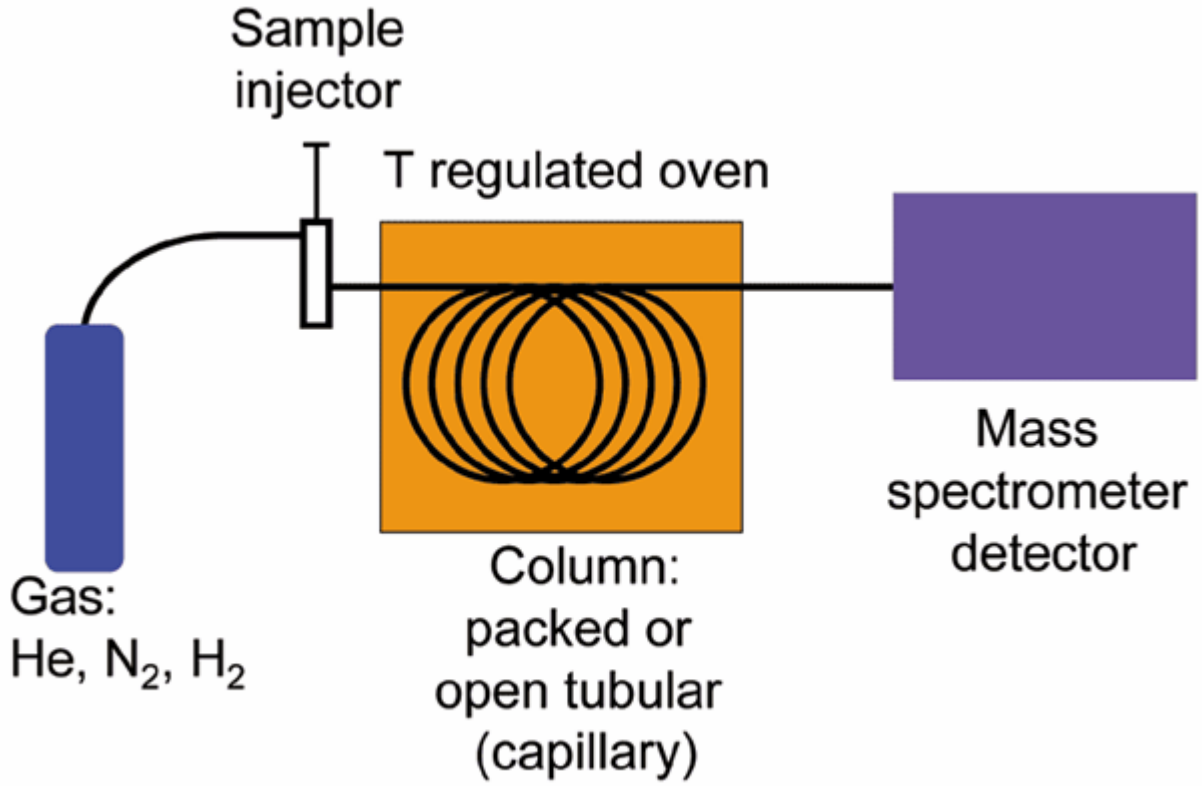
- Gas Chromatography / Mass Spectroscopy
  - some 100000€
  - analyzes any gas

Fourier Transform Infrared Spectroscopy



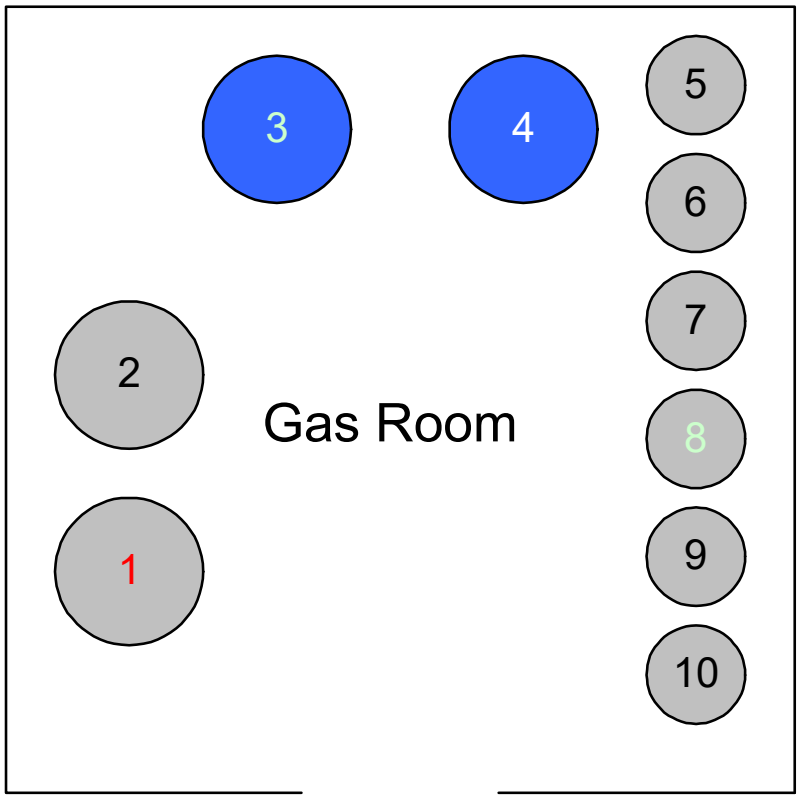
Universal and most Expensive Solution for any Substance: Gas Chromatograph and Mass Spectrometer

(Specific Scientific Purposes Only)



Source: K. Murray, Wikipedia

Infrastructure (Zero Gases, Span Gases, Burn Gas)



1 H_2 in He

2 N_2

3 Synthetic Air

4 O_2

5 CO 9,5 Vol-% in N_2

6 CO 3000 ppm in N_2

7 CO_2 19 Vol-%

8 NO 9500 ppm in N_2

9 Propane 6500 ppm in N_2

10 O_2 22,5 Vol-%