Gas and Vapour analysis

Carbon Dioxide
Volatile Anaesthetics
Measurement of CO$_2$ and VA

- Infrared absorption spectrometry
- Mass spectrometry
- Raman Spectrometry
IR Spectrometry

Dissimilar Molecules and IR Absorption
Infrared spectroscopy

- IR radiation through a sample, some is absorbed by the sample and some of it is passed through (transmitted)

- The resulting spectrum represents the molecular absorption and transmission, creating a molecular fingerprint of the sample
IR Spectrum

- Like a fingerprint no two unique molecular structures produce the same infrared spectrum

- This makes infrared spectroscopy useful for several types of analysis.
No IR Absorption
IR absorption

• Gas molecules that are composed of two or more dissimilar atoms (e.g. CO$_2$, N$_2$O, VA) have bonds between their component atoms

• Certain wavelengths of IR radiation excite these molecules, stretching or distorting the bonds, which also absorb the radiation

• Carbon dioxide molecules absorb infrared radiation at a wavelength of 4.3 µm
IR and partial pressure

• The greater the number of molecules of \( \text{CO}_2 \) present, the more radiation at 4.3 \( \mu \text{m} \) that is absorbed.

• Because the amount of infrared radiation absorbed is a function of the number of molecules present, it is, therefore, also a function of partial pressure. Thus, infrared analyzers measure partial pressure.
Absorption Spectrum

$\text{N}_2\text{O, H}_2\text{O, CO}_2$

Volatile Anaesthetics
Absorption Spectrum

Absorption Spectrum graph showing absorption bands for different gases such as CO$_2$, CO, N$_2$O, and H$_2$O at various wavelengths. The y-axis represents absorption percentage, and the x-axis represents wavelength (λ).
IR Spectrometer
Types

Main Stream

Side Stream
Main stream

- For a respired gas mixture to be analyzed, either the gas must be brought to the analyzer or the analyzer must be brought to the gas in the airway

- Analyzers where gas is not removed from the circuit for analysis elsewhere, is termed a *nondiverting* or *mainstream analyzer*
Advantages and disadvantages

• Require a special airway adapter and analysis module to be placed in the breathing system by the patient’s airway

• Vulnerable to damage and add dead space

• New designs are light in weight (~30gms), have small dead space, and use solid-state technology
Advantages and disadvantages

- Produce sharp capnogram in real time

- Subject to interference by water vapor, secretions, and blood

- Condensed water blocks all infrared wavelengths, leaving too little infrared source intensity to make a measurement, the cuvette’s window is heated (usually to 41°C) to prevent such condensation and interference.
CO$_2$ sample chamber

Windows transparent at required wavelength

I.R source

CO$_2$ sample chamber

Chopper/ filter wheel

Detector

Airway adapter

E.T.T

Breathing system

Main stream
Side stream

• Analyzers where gas to be analyzed can be sampled continuously from the vicinity of the patient’s airway and conducted via fine-bore tubing to the analyzer unit is termed a diverting, or side stream sampling

• Can be of any size and therefore offer more versatility in terms of monitoring capabilities
Side stream

- Sampling via an adapter placed between the circuit and the patient’s airway and passes through a water trap before entering the analyzer.

- Gas sampling flow rate is usually about **200 mL/min** (range of 50 - 250 mL/min).
Problems with sidestream

Problems with the catheter sampling system, such as

• Clogging with secretions or water
• Kinking
• Failure of the sampling pump
• Slower response time (although usually < 3 sec)
• Artifacts when the gas sampling rate is poorly matched with the patient’s inspiratory and expiratory gas flow rates
Response

Step change in gas concentration

Delay

Response

Analysers Phases

Analysers Response

100%

90%

0
Delay and Rise Time

- Delay time (transit time, response time, transport delay, time delay, lag time) is the time to achieve **10% of a step change** in reading at the gas monitor.

- Rise time (response time) is the time required for a change from **10% to 90% of the total change** in a gas value with a change in concentration at the sampling site.
Importance

• Total system response time $= \text{Delay time} + \text{Rise time}$

• A fast response time is necessary to obtain accurate values and waveforms

• The use of an instrument with a slow response may result in incorrect end-tidal values during rapid ventilation.
Capnograph

- **A End- Inspiratory**
- **B Dead space gas exhaled**
- **C Alveolar gas exhalation starts**
- **D Closing Volume reached**
- **E Inspiration starts**

The graph shows the percentage of CO2 (% CO2) across different phases of respiration.

**Axes:**
- Y-axis: % CO2
- X-axis: Points A, B, C, D, E

Points:
- A: End- Inspiratory
- B: Dead space gas exhaled
- C: Alveolar gas exhalation starts
- D: Closing Volume reached
- E: Inspiration starts
Uses
Uses

- Confirmation of ETT placement
- Detection of rebreathing due to:
  - Normal feature of circuit, e.g. Bain
  - Exhausted soda lime
  - Faulty expiratory valve
- Detection of hypo- & hyper-ventilation
- Early detection of circuit disconnection
- Early detection of airway obstruction
- Detection of circuit leaks
Limitations
Limitations

• Interference from other gases: N\textsubscript{2}O, H\textsubscript{2}O

• Unreliable readings if RR>60

• Does not monitor adequacy of oxygenation

• Monitors symptoms rather than causes

• EtCO\textsubscript{2} does not always parallel PaCO\textsubscript{2}
Sources of Error
Sources of error

• Affected by **ambient pressure**: Partial Pressure

• \( \text{O}_2 \) and \( \text{N}_2 \) **broaden the absorption band** of \( \text{CO}_2 \),
  – Slightly lowering the values (0.5% decline with 95% \( \text{O}_2 \) present)
  – Compensated electronically
Sources of Error

• **Electronic drift:**
  – Reduced by interrupting current flow to LED (100 Hz) and by rotating chopper wheel

• **$\text{N}_2\text{O}$ and $\text{H}_2\text{O}$ absorption:**
  – Spectrum overlaps that of $\text{CO}_2$
  – Causes falsely high readings (0.1% per 10% $\text{N}_2\text{O}$)
  – Compensated electronically
MASS SPECTROMETRY

Using magnetic field and charge
Mass spectrometer

• The analyzer unit separates the components of a stream of charged particles (ions) into a spectrum according to their mass/charge ratios.

• The relative abundance of ions at certain specific mass/charge ratios is determined and is related to the fractional composition of the original gas mixture.
• The creation and manipulation of ions is carried out in a **high vacuum** (1/100,000 mmHg) to avoid interference by outside air and to minimize random collisions among the ions and residual gases.

• Gas continuously drawn by a **sampling pump** from an airway connector via a long nylon catheter.
During transit, the pressure decreases from atmospheric (usually 760 mmHg) in the patient circuit to approximately 40 mmHg by the inlet of the analyzer unit.

A very small amount of the gas actually sampled from the circuit (approximately $10^{-6}$ mL/sec) enters the analyzer unit’s high-vacuum chamber through the molecular inlet leak.
The gas molecules are then bombarded by an **electron beam**, which causes some of the molecules to **lose one or more electrons** and become **positively charged** ions.

Thus an oxygen molecule ($O_2$) might lose one electron and become an oxygen ion ($O_2^+$) with one positive charge. The mass/charge ratio (often termed m/z) would therefore be $32/1$, or $32$. 
• If the oxygen molecule lost two electrons, it would gain two positive charges and the resulting ion (\(\text{O}_2^{2+}\)) would have an m/z of 32/2, or 16

• The process of electron bombardment also causes large molecules (e.g. halothane, enflurane, isoflurane) to become fragmented, or cracked, into smaller, positively charged ions
Principle

Anode

Cathode

Dispersion chamber

Dispersion according to mass

Low vacuum chamber

High vacuum chamber

Ion detection plate

Signal processing and display
The positive ions created are focused into a beam by the **electrostatic fields** in the ion source, directed through a slit to define an exact shape for the beam, and **accelerated and directed** into the field of the permanent magnet.

The **magnetic field** influences the direction of the ions, causing each ion species to curve in a trajectory whose arc is related to its m/z.
Magnetic sector

• The effect is to create several separate ion beams exiting the magnetic field

• The separated beams are directed to *individual collectors*, which detect the ion current and transmit it to amplifiers that create output voltages in relation to the abundance of the ion species detected by each collector.
Magnetic sector

- The collector plates are positioned so that an ion with a specific m/z ratio strikes a **specific collector**

- The **heaviest ions** are deflected the **least** and travel the farthest before striking a collector. Collectors for these heavy ions are therefore located furthest from the ion source
Magnetic sector

- Powerful magnetic field
- Heaviest ions
- Lightest ions
- Separate detectors for each ion species
Quadrupole mass

• Four rods with opposite pairs electrically connected

• By *careful tuning of the radio frequency* component of the magnetic field, only ions of a given mass x charge ratio proceed through the quadrupole to the detector, all other ions oscillating and colliding with the device
Quadrupole mass

• By a combination of *changing the voltage* on the acceleration plate and *of judiciously tuning the magnetic field* a spectrum of mass x charge components can be detected and quantified.

• By *scanning at 50 Hz*, it is possible to produce continuous record of gas concentrations.
Quadrupole

Electrodes

Single detector
Using LASERS
Raman Spectrometer
Laser Sample Collection optics Filter removing unshifted $\lambda$ Focusing optics Photomultiplier detector microprocessor Display Gas Cell (Part of LASER tube) Raman line Filter Filter removing unshifted $\lambda$ Collection optics Laser Sample
Raman spectroscopy

• A Helium– Neon LASER emits monochromatic light at a wavelength of 633 nm

• When this light interacts with the intramolecular bonds of specific gas molecules, it is scattered and re-emitted at wavelengths different from that of the incident monochromatic light
RS and partial pressure

• Each re-emission wavelength is characteristic of a specific gas molecule present in the gas mixture and therefore is a function of its partial pressure

• Thus, Raman spectroscopy also measures *partial pressures*
VA Monitoring

Historical
Methods of analysis

• Interferometry (Light wave interference): e.g. Riken gas indicator

• Surface absorption (silicone rubber): e.g. Drager Narcotest Halothane indicator

• Ultraviolet: e.g. Hook and Tucker Halothane meter
Methods of analysis

- Photo-acoustic spectroscopy (sound waves): e.g. Bruel and Kjaer anaesthetic gas monitor

- **Piezoelectric**: e.g. Engstrom Emma anaesthetic vapour analyser.
Riken gas indicator
Drager Narcotest Halothane indicator
Engstrom Emma
Brue and Kjaer anaesthetic gas monitor
Miran IR Spectrometer
An early gas monitor
## Summary

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<thead>
<tr>
<th>Technique</th>
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<tbody>
<tr>
<td></td>
<td>O₂</td>
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<tr>
<td>IR Spectrometry</td>
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<td>IR Photoacoustic</td>
<td>√</td>
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<td>Mass spectrometry</td>
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