Anaesthesia Gas Monitoring

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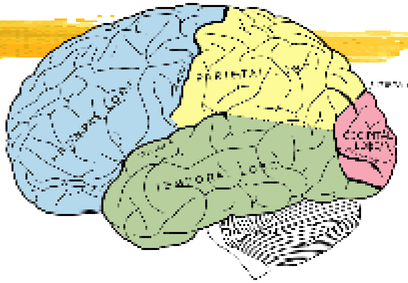
Why anaesthesia gas monitoring

- The ability to rapidly measure concentrations of inspired and expired gas is of paramount importance in anesthetic practice.
- Oxygen
- CO_2
- N_2O
- Inhalational anaesthetics

- New technologies: low size and weight, cost
- Present in the most of modern op. rooms

Alveolar vs brain concentration



Depth of anaesthesia?

Brain concentration of inhalation agent??

Rapid equilibration alveolus – blood – brain

Alveolar concentration – end expiratory exhaled gas

Let us measure it

Minimum Alveolar Concentration

Alveolar (or end-expiratory) concentration at which 50% of patients will not show a motor response to a standardized surgical incision.

The standard deviation of MAC is ~10%, thus

95% of patients will not respond to 1.2 MAC, and

99% will not respond to 1.3 MAC

MAC-awake - the value necessary to prevent voluntary response to command.

MAC-BAR - blocks autonomic response (BAR) to surgical stimulation.

MAC-intubation - value that prevents response to ETI.
It is about 1.3 MAC.

Monitoring of gases

- Patient safety first!
- Information about concentration, reached MAC, overdose, wrong agent.....
- Gas monitoring: Standard??

- ASA closed Claims Database:
  gas delivery equipment 2%; 21% vaporisers; mostly overdose and awareness.
  Most injuries preventable by using monitors.

Caplan 1997

Why basics of technology

- As anaesthetists we must be aware of:
  - basic physical principles involved in these monitors
  - their limitations
  - advantages
  - disadvantages.

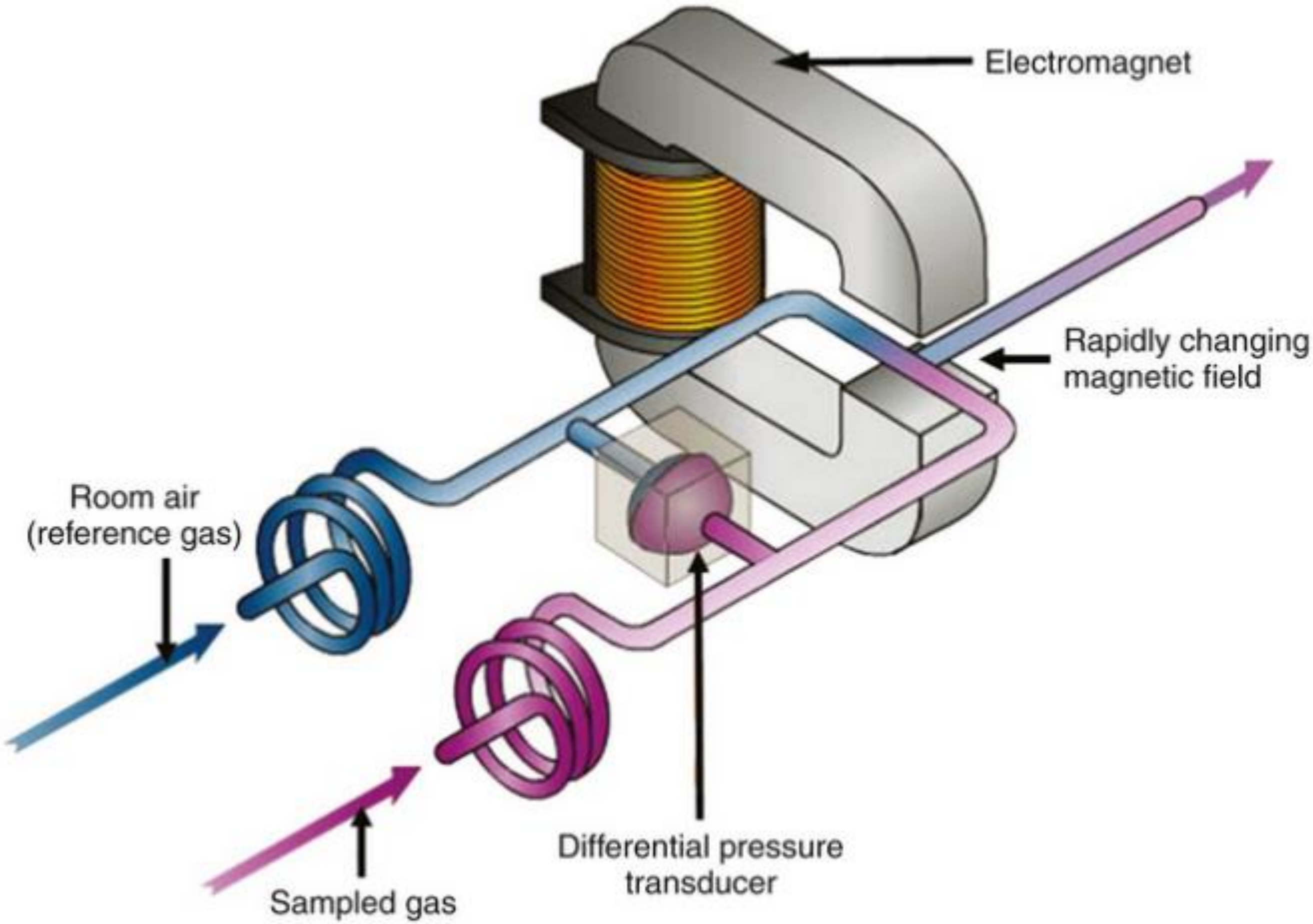
1. Oxygen analysis

- Goal: to detect
  - hypoxia
  - hyperoxia
  - disconnection
- Usually placed on inspiratory arm
- In the past:
  - Mass spectroscopy
  - Raman spectroscopy
- Today two physical methods:
  1. Paramagnetic analysis (Pauling sensor)
  2. Electrochemical analysis
     fuell / galvanic cell; polarographic

A. Paramagnetic analyzers

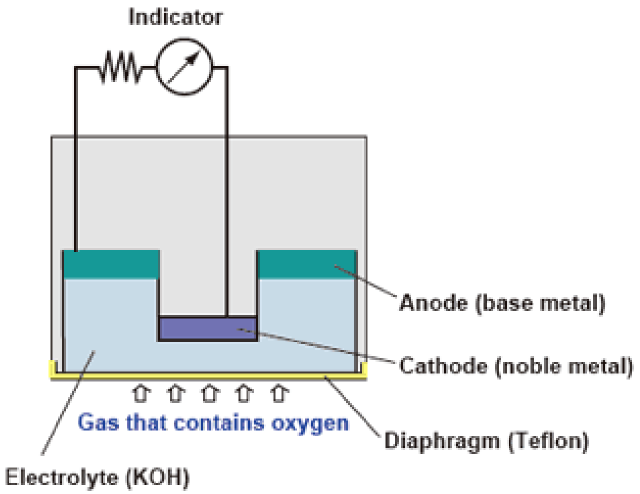
- O_2 is a **paramagnetic** gas – 2 unpaired electrons on outer orbit
- It is attracted by the rapidly changing magnetic field.
- O_2 and reference gas are pumped into an **electromagnetic field**.
- Between gases there is a sensitive pressure sensor.
- When O_2 molecules **realign** themselves to the magnetic field a **pressure wave** is **generated** and sensed by the sensor.
- This is then converted to an **electrical signal** proportional to the O_2 **partial pressure.** Displayed as Vol%.

Paramagnetic O_2 analyser



B. Electro chemical analyzers

- Electro chemical analyzers have two parts:
  - sensor containing the **cathode** and an **anode** enclosed in a **membrane** permeable to gases
  - an analyzer box with electronic circuitry, display monitor and alarm.
- Two physical principles are used in electrochemical analysis.
  1. Galvanic / fuell cell
  2. Polarographic electrode



Electro chemical analyzers I

1. Galvanic cell / Fuel cell

The sensing electrode is a **silver** cathode where oxygen molecule is reduced to a hydroxide ion ($O_2 \Rightarrow OH^-$) due to a chemical reaction.

The hydroxide ion then reacts with a **lead** anode giving up electrons (battery generating a voltage proportional to the oxygen fraction).

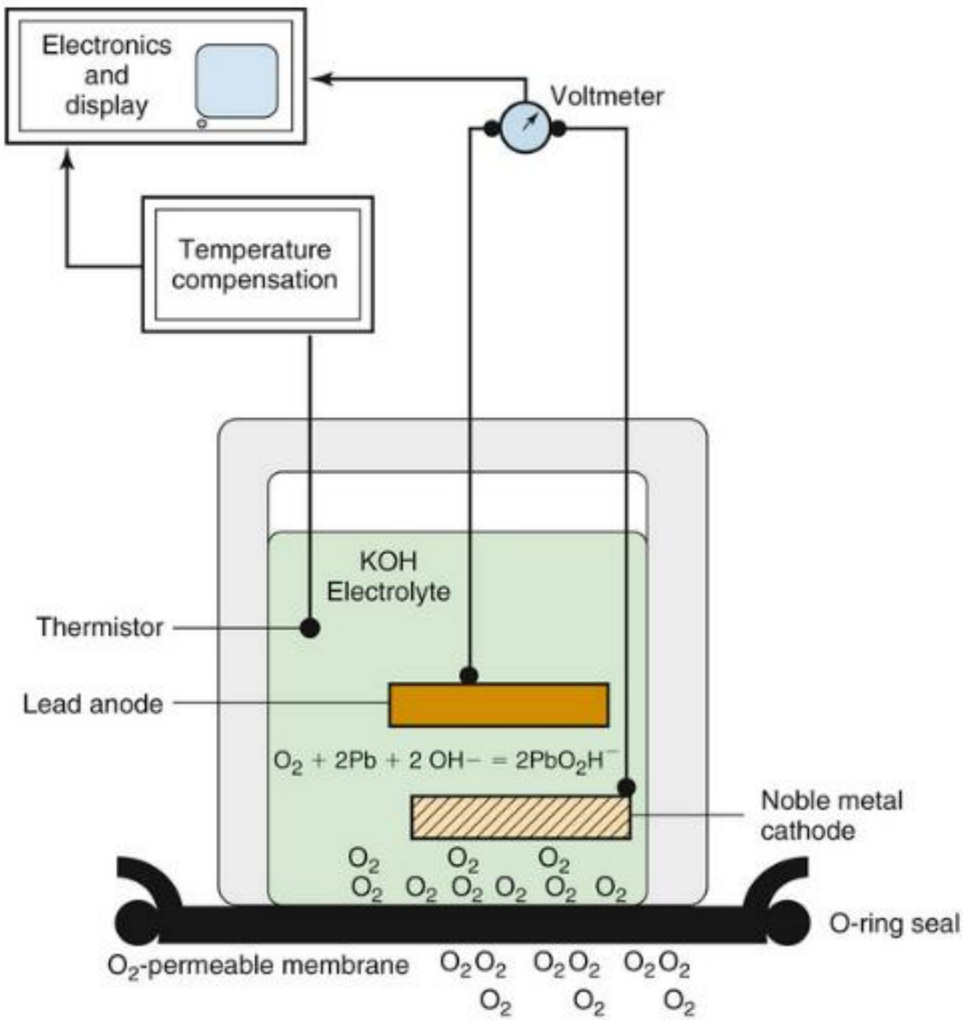
$$2OH^- + Pb \Rightarrow PbO + H_2O + 2e^-$$

The **electronic current** is sensed by a meter and is **proportional** to the **partial pressure** of oxygen.

These require regular replacement of galvanic sensor capsule.

Lifetime: depends on concentration and time exposition to oxygen

Fuel cell analyser



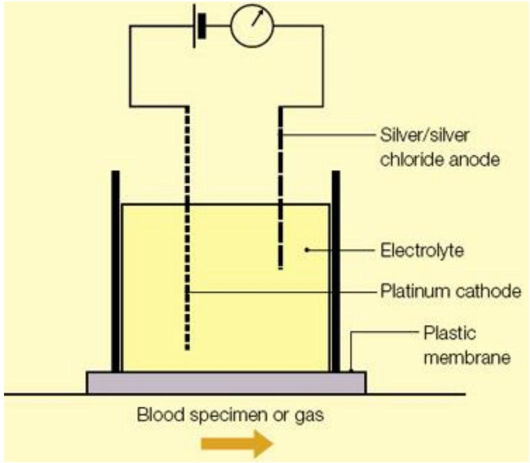
Electro chemical analyzers II

2. Polarographic electrode (Clark)

Oxygen diffuses via a **membrane and electrolytes** to the **cathode** and a similar reaction as above takes place.

The ***current change*** is **proportional** to the **number** of **oxygen** molecules surrounding the electrode.

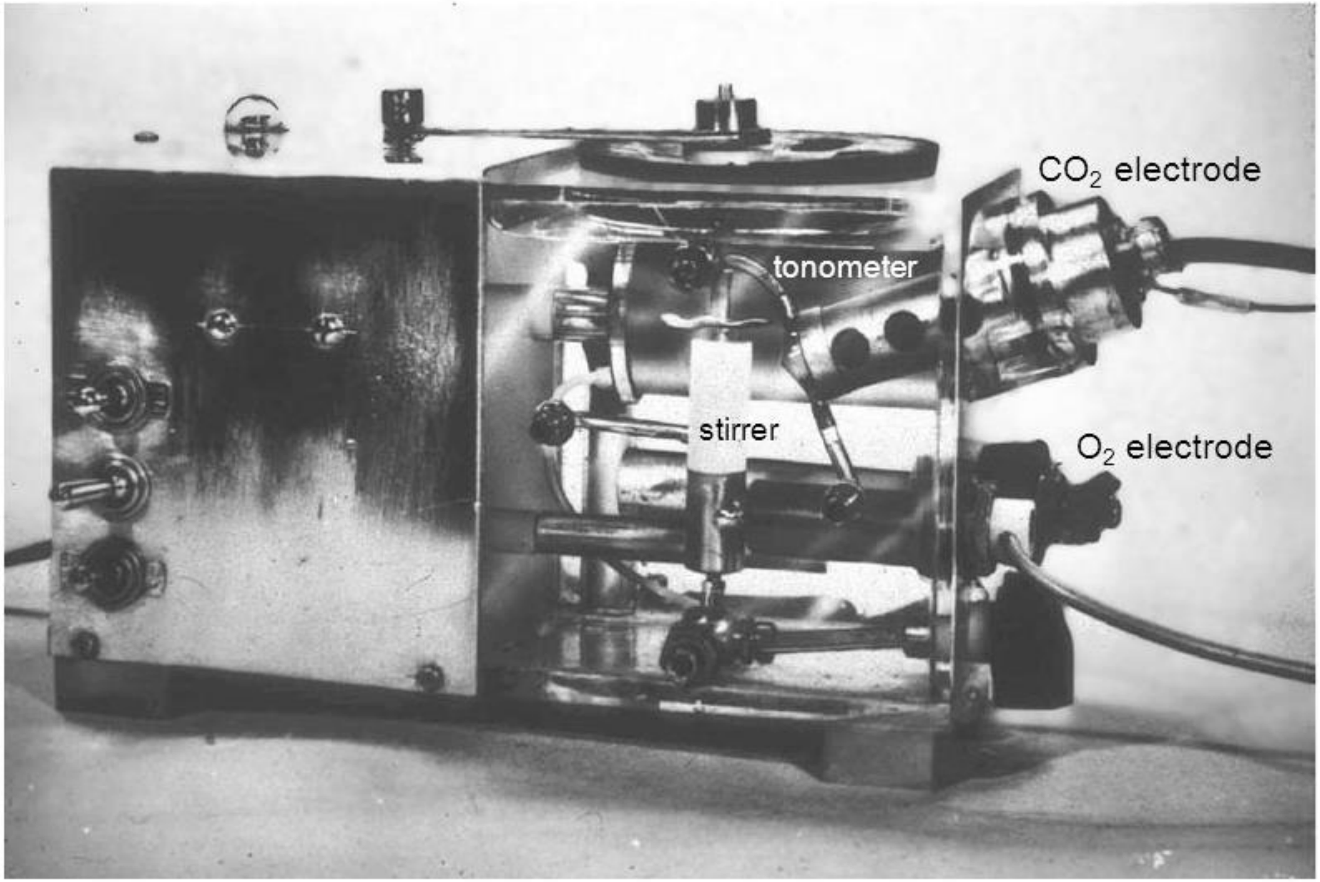
Main difference from fuel cell is that a polarizing **voltage** is applied by an external source.



Clark´s electrode

First blood gas apparatus. Severinghaus and Bradley (1958)

O_2 electrode consumed so much oxygen it needed stirring and calibration with equilibrated blood.



Oxygen polarographic electrode

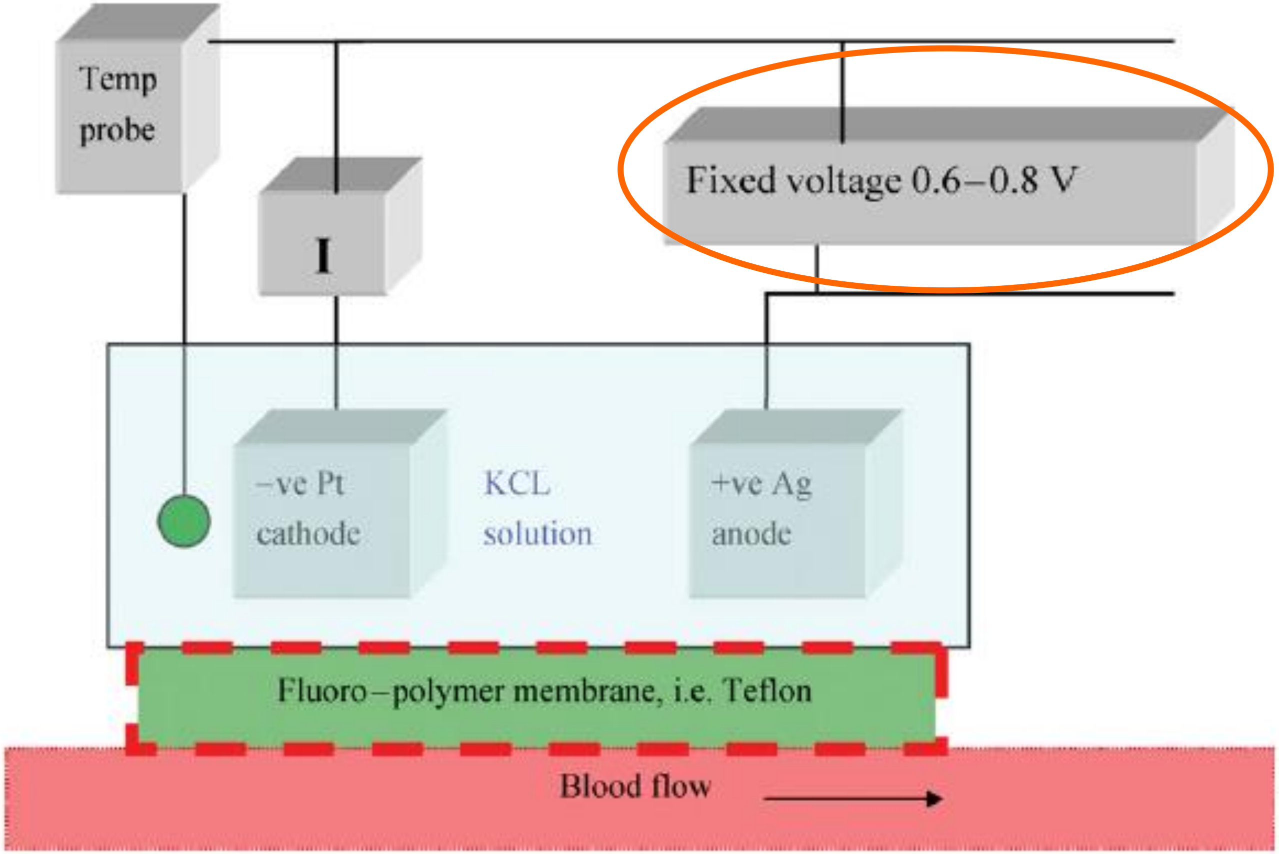


Fig. 2 Polarographic cell. I, ammeter, amplifier and processor; Pt, platinum; Ag, silver; KCl, potassium chloride solution.

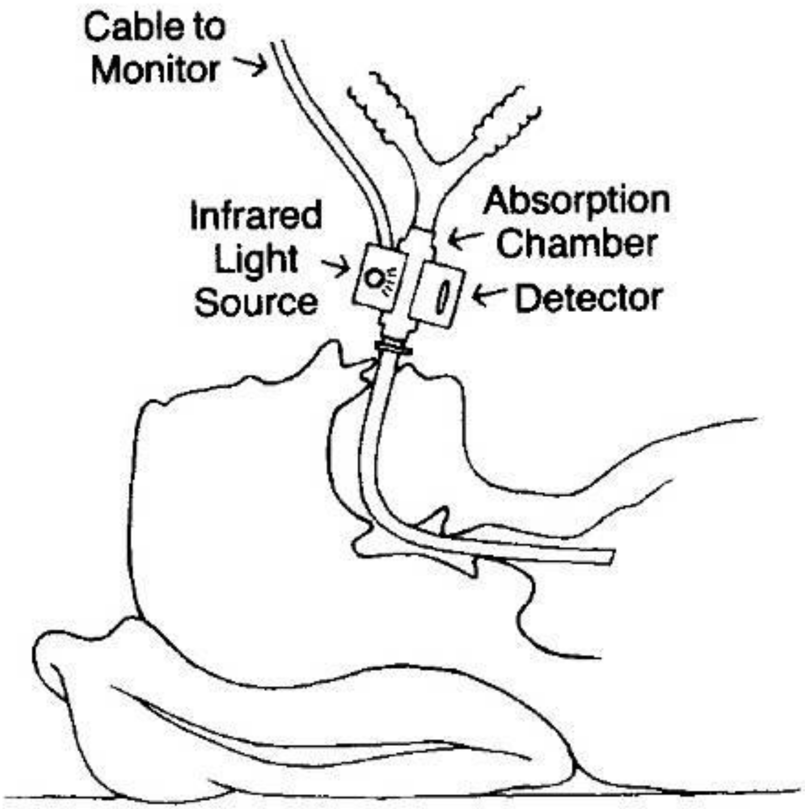
Langton 2009

Table 1: Technique, principle and limitations of oxygen analysers in anaesthesia machines

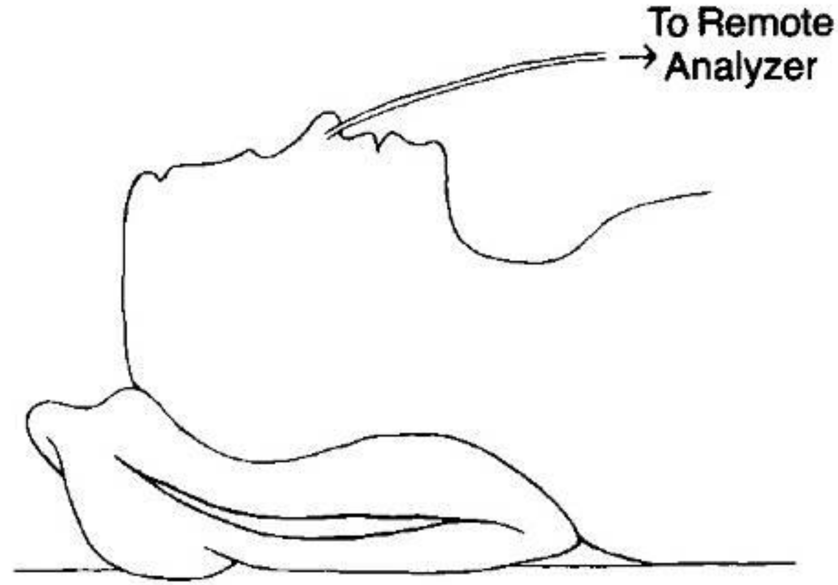
Technique	Principle	Limitations
Paramagnetic oxygen analyser	Oxygen being paramagnetic because of unpaired electron is attracted in a magnetic field	Affected by water vapours and requires water trap
Galvanic oxygen analyser (Fuel cell, Hersh Cell)	Based on a chemical phenomenon generated by oxygen molecules	Limited life span
Polarographic oxygen analyser (Clark electrode)	Based on a chemical phenomenon generated by oxygen molecules	Requires replacement because of limited life span of Teflon

Anaesthesia gas analysis

Sensors for monitoring of gases

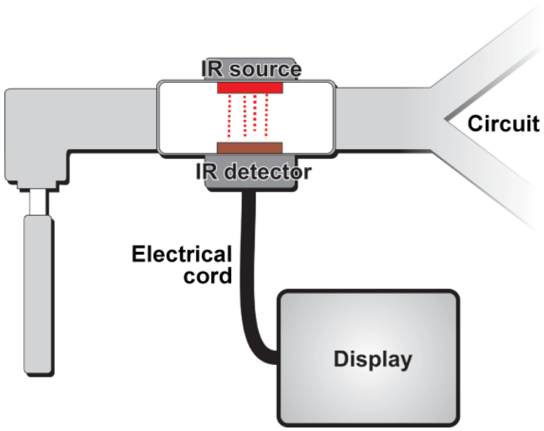


Mainstream Capnometry



Side-Stream Capnometry

Sensors - main stream



Advantages

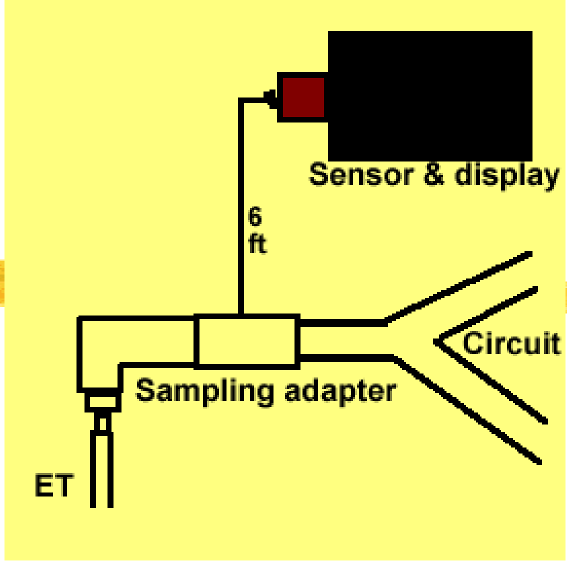
- No sampling tube, no obstruction
- No delay in recording
- Suitable for neonates and children

Disanvantages

- Weight of senser - traction on the endotracheal tube.
  - *the newer sensors are light weight*
- Facial burns. *- eliminated with newer sensors*
- No measurement of other gases
- Sensor windows may clog with secretions*. - they can be replaced easily as they are disposable.*
- Difficult to use in unusual patient positioning such as in prone positions.
- Need of sterilization problem. *- the newer versions use disposable sensor windows*

Currently only CO_2 can be measured by mainstream monitors

Sensors - side stream



Advantages

- Easy to connect, no weight
- No problems with sterilization
- Can be used in awake, non intubated patients
- Simultaneously measurement of more gases
- Easy to use when patient is in unusual positions (prone)
- In collaboration with simultaneous oxygen administration via a nasal prong

Disadvantages

- Return of gases in anaesthesia (50-300 cc)
- Delay in recording due to movement of gases from the ET to the unit
- Sampling tube obstruction (water, secretion)
- Calibration needed

Anaesthesia gas analysers

- Size
- Side / main stream
- Breath to breath analysis
- Response time
- Accuracy
- One / multiple gas; specificity
- Water sensitivity
- Calibration

Gaseous analysis
CO_2, NO_2, volatile anaesthetics

1. Mass spectrometry
2. Roman scattering
3. Refractometry
4. Piezoelectric absorption
5. Infrared absorption spectroscopy

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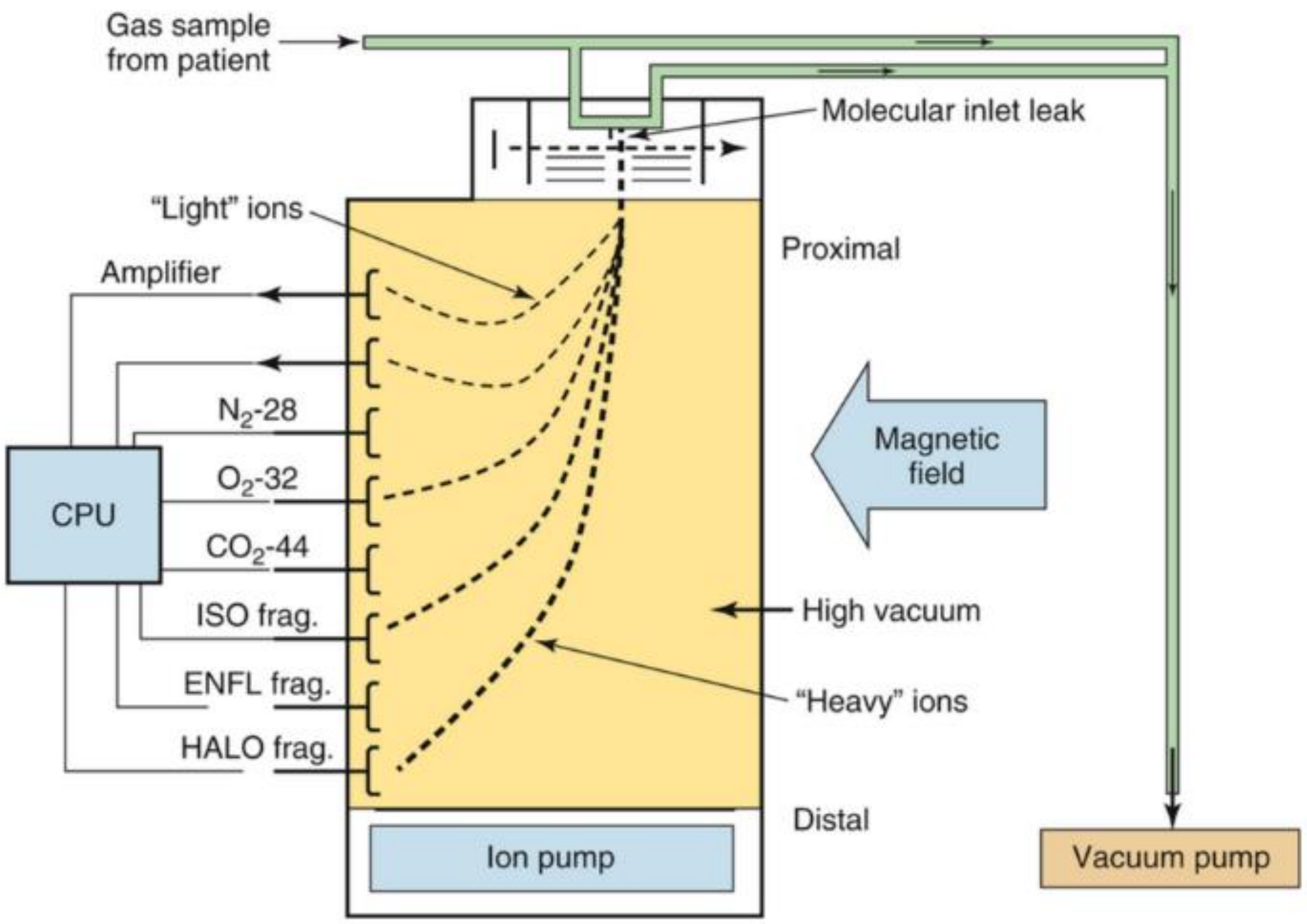
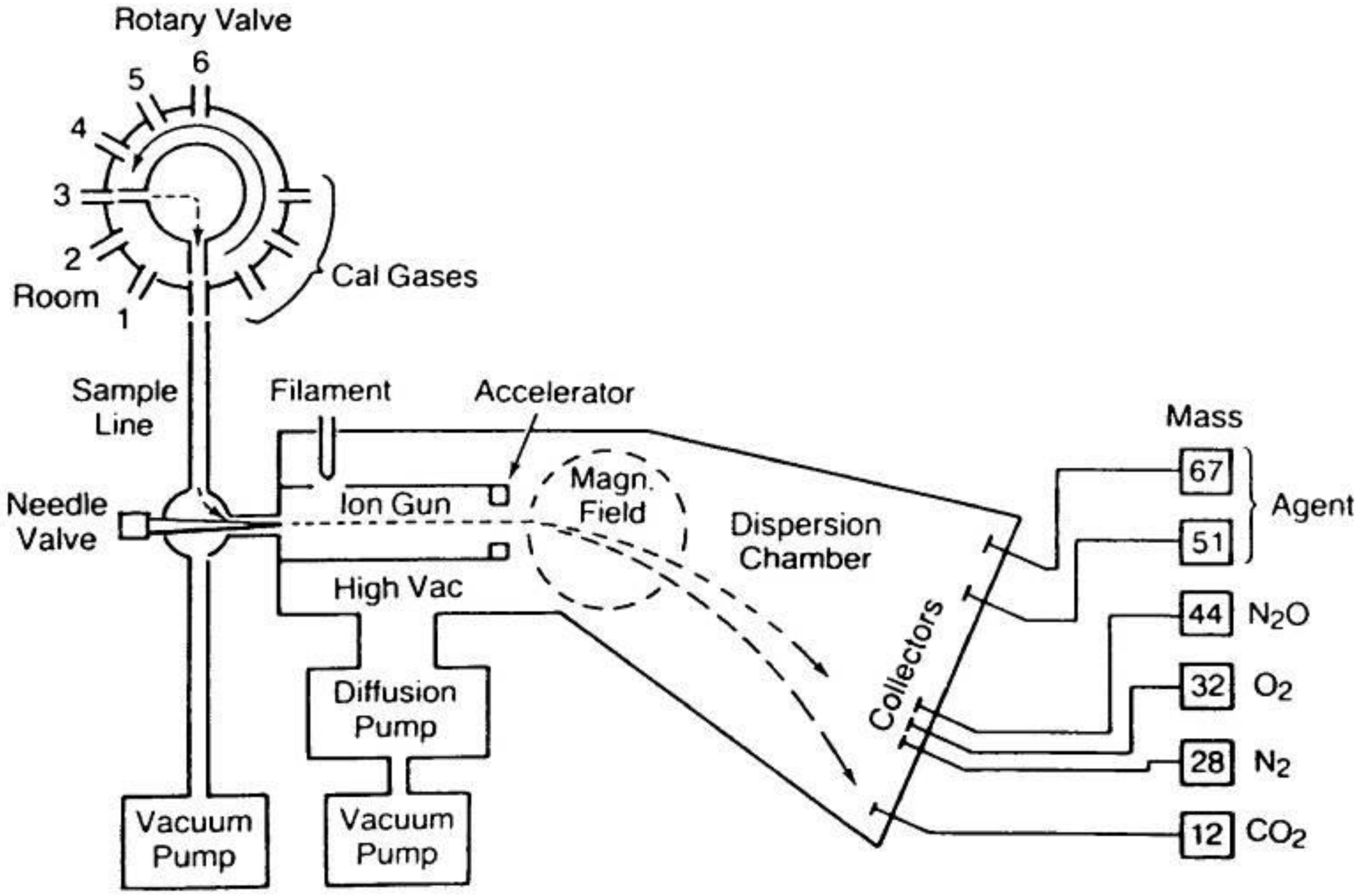
1. Mass spectrometry

- 1960´ NASA programme
- 1970´ centrally located for more theatres; later smaller size, in operating theatres
  1981: Ohmeda 6000 – stand alone, continuous
- Identification of gases according the molecule mass
- Side stream, vacuum chamber, ion gun, molecule fragments, trajectory bending, detection electrodes
- Calibration for every molecule
- 1980´new multigas analysers, different technologies

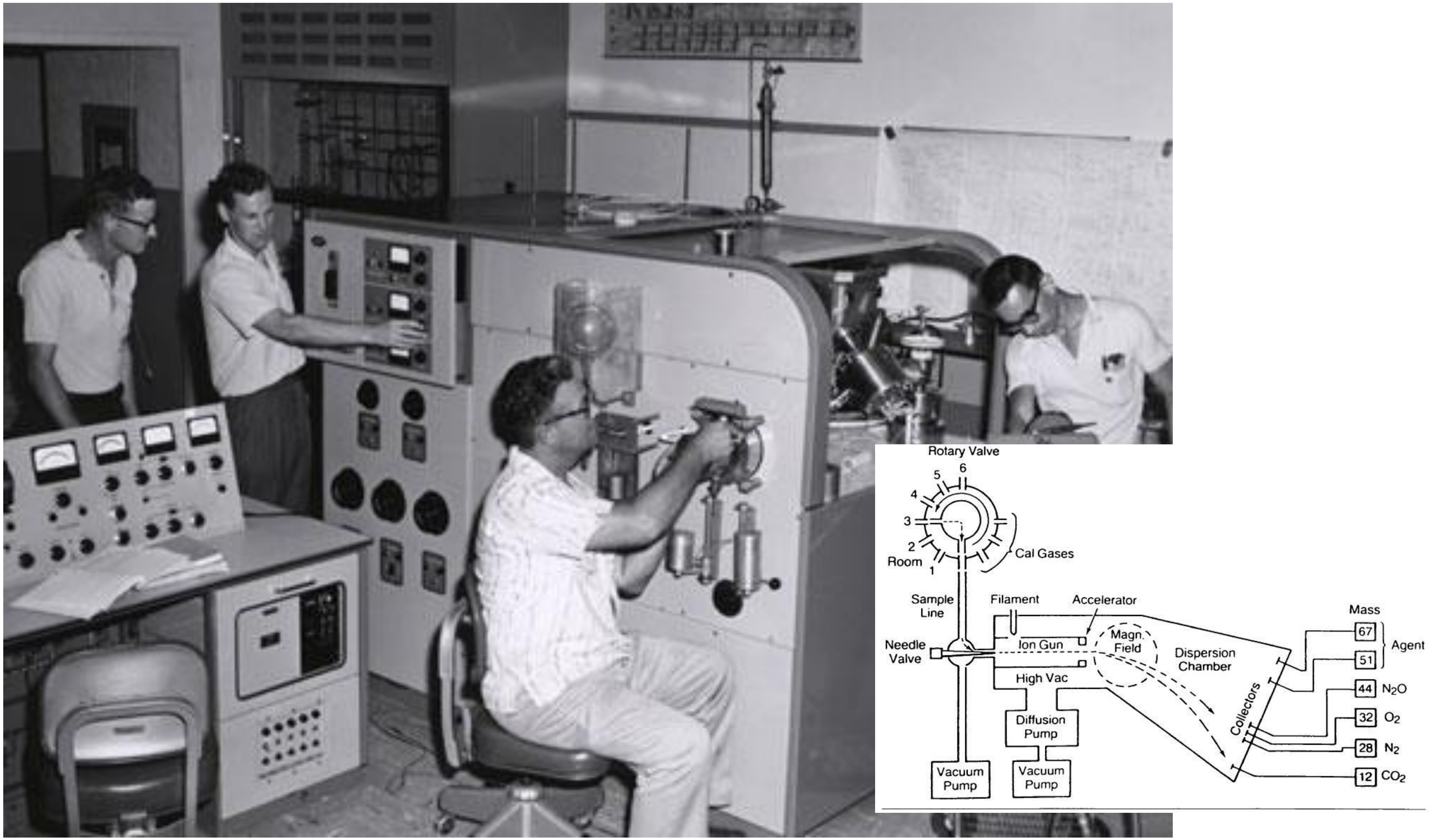
Mass spectrometry



Mass spectrometry



Monitorovanie plynov
Hmotnostný spektrometer 1963



Mass spectrometry

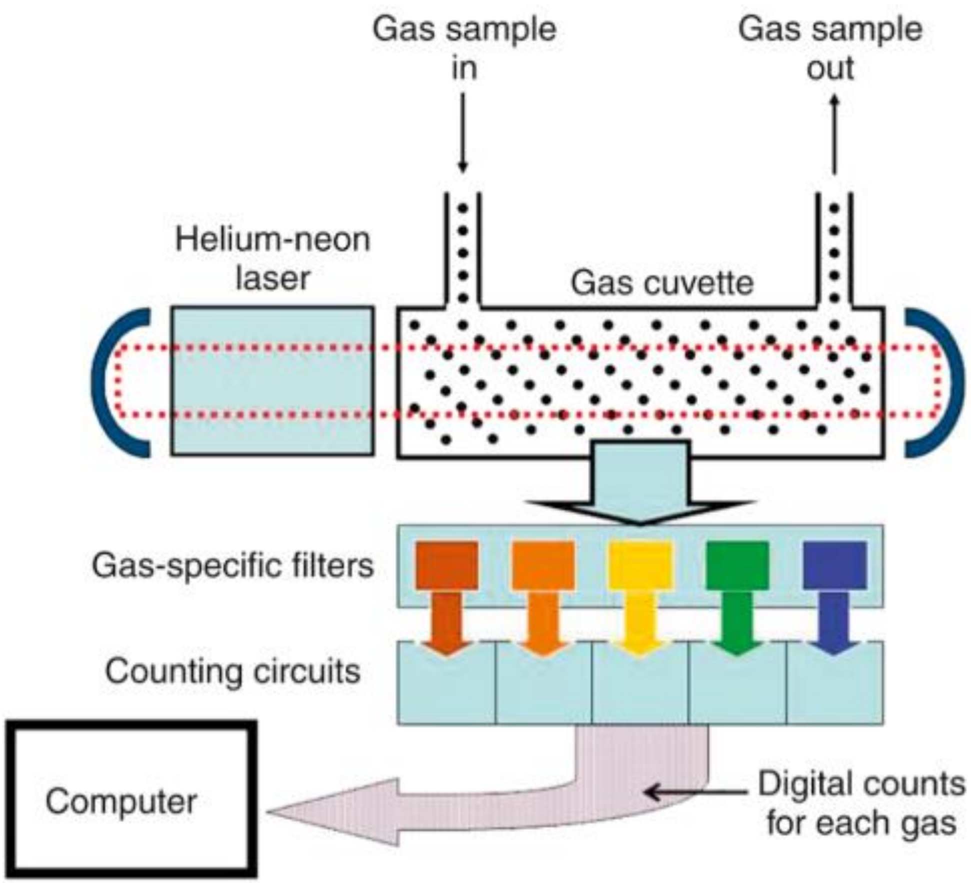
- Advantages:
  - rapid response
  - wide range of gases (helium, nitrogen)

- Disadvantages:
  - bulk, expensive
  - discontinuous

Raman scattering

- Intense, coherent, monochromatic light (*laser*)
- Gas molecul will scatter the light, some will be absorbed
- Narrowband filters, photodetector and signal processing unit.
- Fast response time, multiple agents, accurate (better than IR)

2. Raman spectroscopy



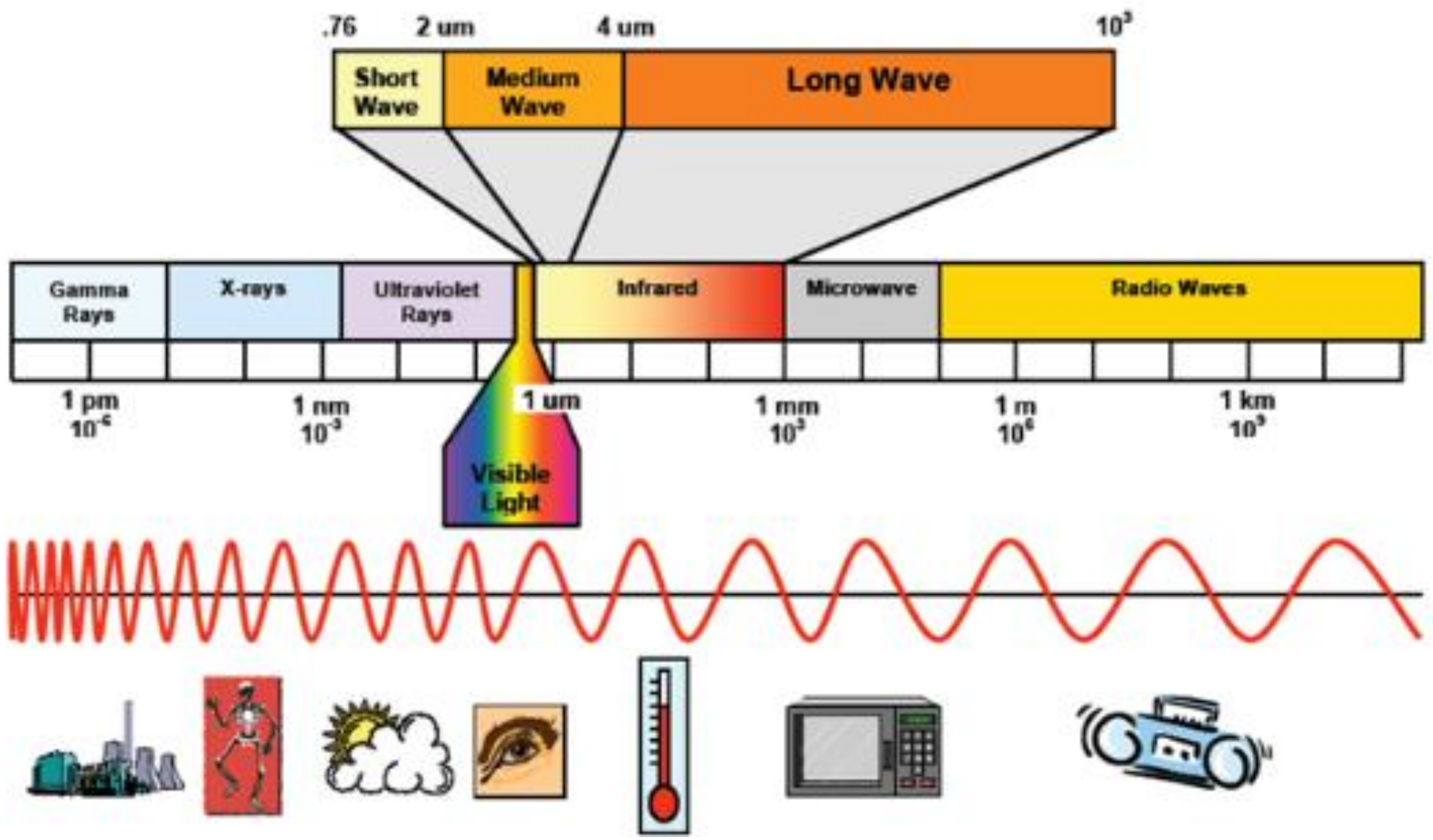
3. Refractometry

- The refractive number of gas must be known. A light beam is split; one portion passes through a chamber containing sample gas, second passes via an identical chamber.
- Beams are recombined and the difference in refraction is compared to a scale.
- Not for breath to breath analysis.
- Mainly used for calibration of vaporizers.

4. Pizoelectric crystal adsorption

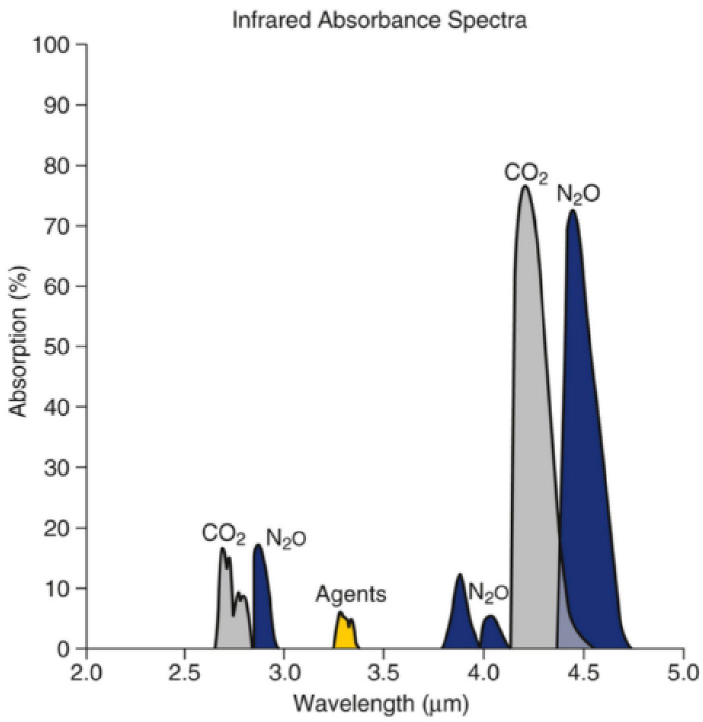
- A quartz crystal with surface coated with lipids vibrates at a specific frequency when stimulated with an electrical voltage.
- When this crystal is exposed to an inhalational agent it absorbs it and its mass changes resulting in a decrease in vibrating frequency.
- An electrical signal is generated which is proportional to the concentration of agent.
- The accuracy is 0.1% but the method is sensitive to water vapour.
- It is compact, fast and is used for breath by breath analysis. Only one agent can be measured and the device cannot discriminate between agents.

5. Infrared spectroscopy



Absorption bands of respiratory gases in the infrared spectrum

- Carbon dioxide, nitrous oxide, and anesthetic gases exhibit absorption of radiation at unique bands in the IR spectrum.
- CO_2 between 4.2 and 4.4 μm
  N_2O between 4.4 and 4.6 μm
  and less strongly at 3.9 μm
- The volatile anesthetic at 3.3 μm and 8.0 to 13 μm

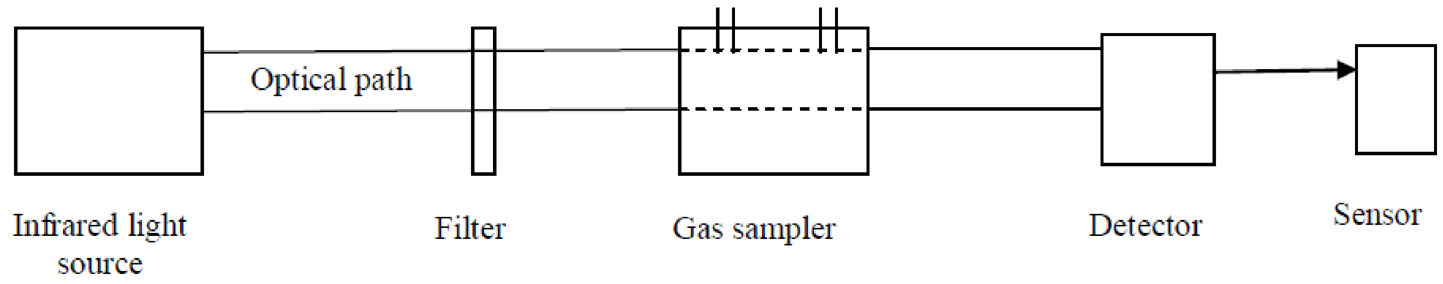


IR spectrometry

- The shorter IR spectrum range 0.76 μm - 13 μm.
- Measurement of the energy absorbed from a narrow band of wavelengths of IR radiation as it passes through a gas sample can be used to measure the concentrations of certain gases.
- Asymmetric, **polyatomic**, polar molecules - such as carbon dioxide, nitrous oxide, water, and the potent volatile anesthetic agents - absorb IR energy when their atoms rotate or vibrate asymmetrically; this results in a change in dipole moment, the charge distribution within the molecule.
- The nonpolar molecules argon, nitrogen, helium, xenon, and oxygen do not absorb IR energy.
- Detector: photocell, thermopiles

IR analysers

- **A. Dispersive:**
  - single optical filter, prism or diffraction to separate the component wavelenghts for **each agent**
- **B. Non dispersive:**
  - multiple narrow-band optical filters through the IR emission is passed
  Mostly used



Dispersive analyzer

- After passing through the gas sample, the radiation emitted by an IR source is separated or dispersed, into the component wavelengths and is arranged sequentially.
- By examining the entire spectrum, a plot of absorbance versus wavelength is obtained, from which the gas composition can be analyzed and quantified, provided the gases in the mixture have characteristic absorption peaks.

Nondispersive analyzer

- Radiation from the IR source is filtered to allow passage of only the specific wavelength bands, for which the gases of interest have distinct absorption peaks.
- The gas sample is placed between the filter and the IR detector or between the IR source and the filter

- IR analyzers used clinically are predominantly of the **nondispersive** type.

A simple nondispersive IR analyzer

A source of IR radiation. Heating the black body causes emission of IR radiation.

A sample cell, or cuvette. The gas to be analyzed is drawn through the cuvette by a sampling pump.

A detector that generates an output signal. The signal is related to the intensity of the IR radiation that falls on it.

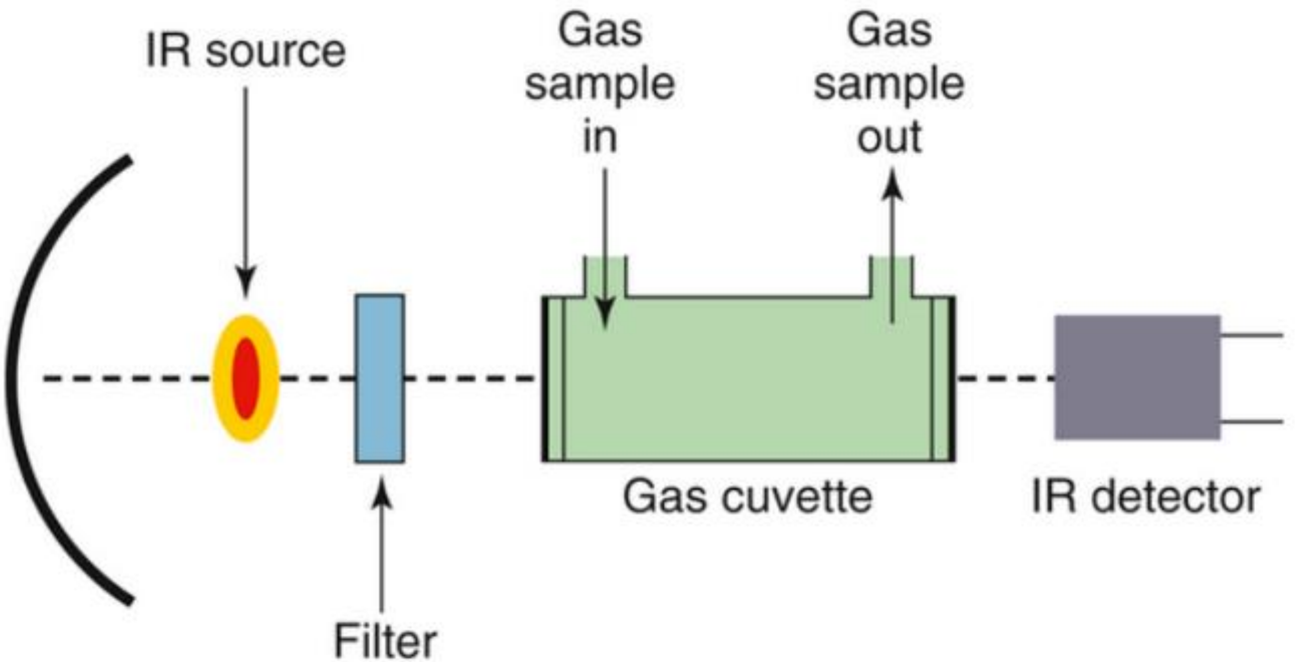
A narrow-band pass filter. This filter allows only radiation at the wavelength bands of interest to pass through

It is interposed between the IR source and the cuvette or between the cuvette and the detector.

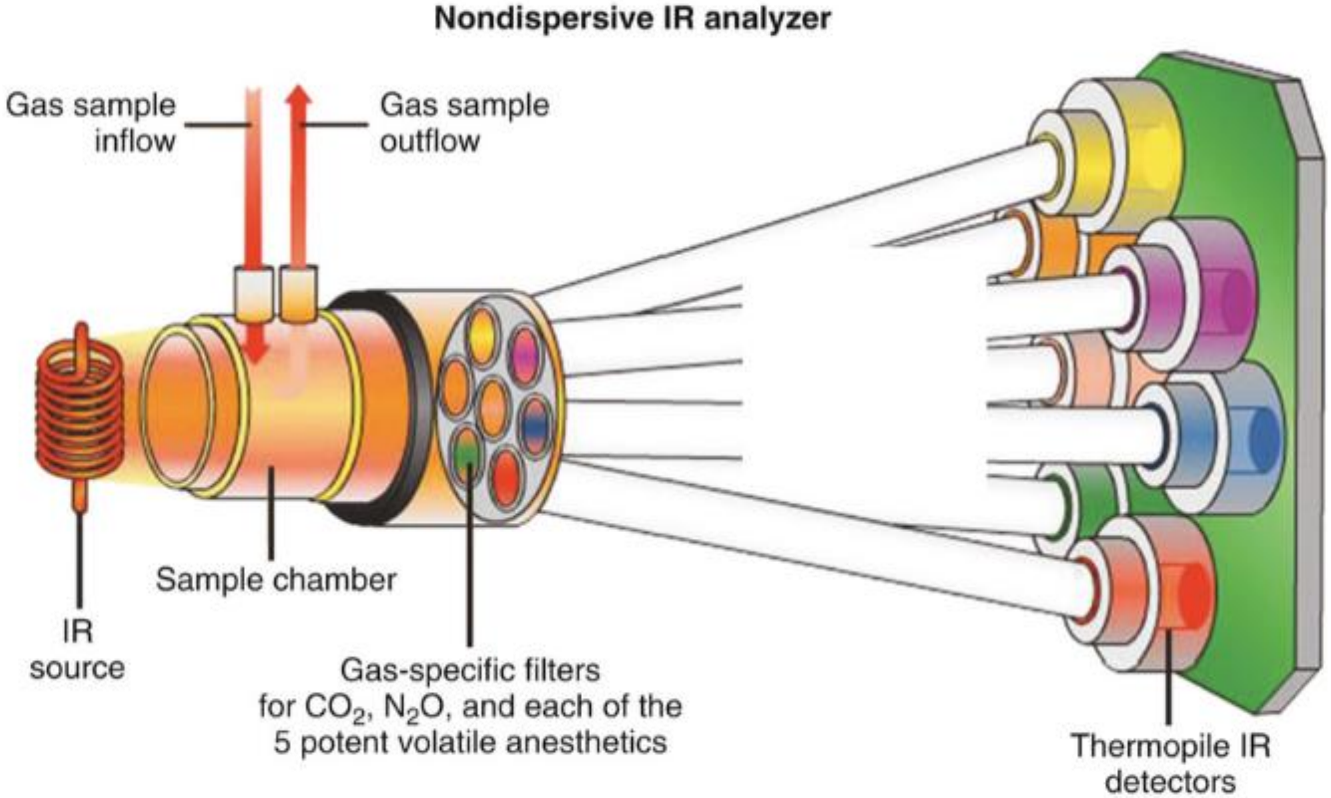
The intensity of radiation reaching the detector is inversely related to the concentration of the specific gas being measured.

Nondispersive analyser

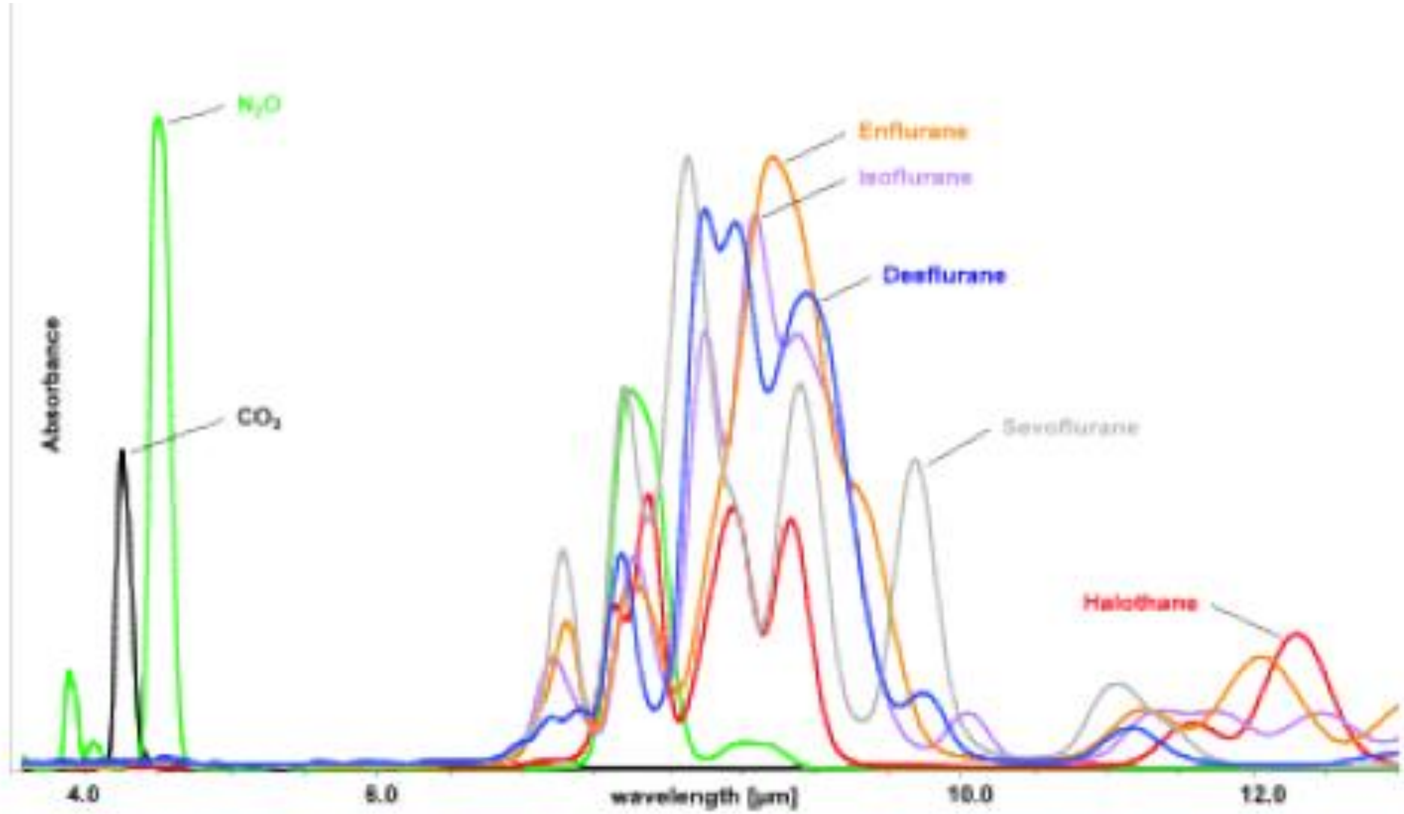
Single-Beam Single-Filter Infrared Analyzer



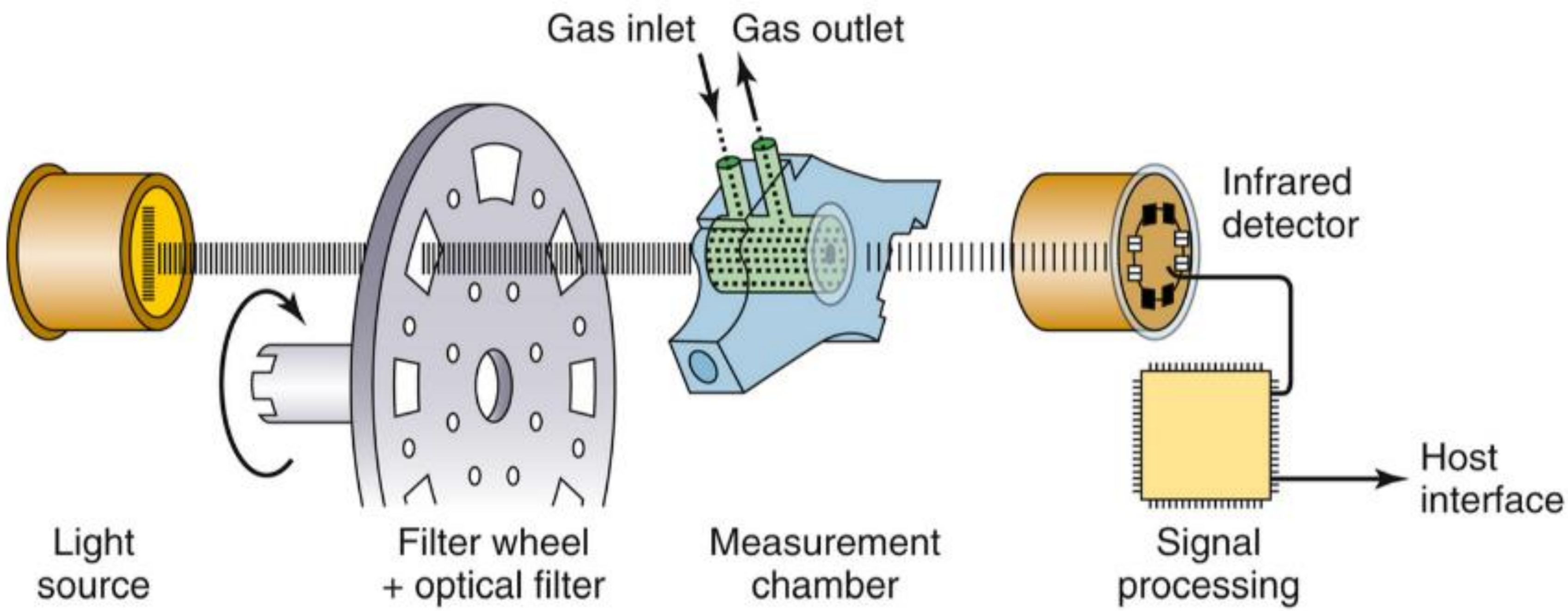
Nondispersive analyser



Absorbance spectra

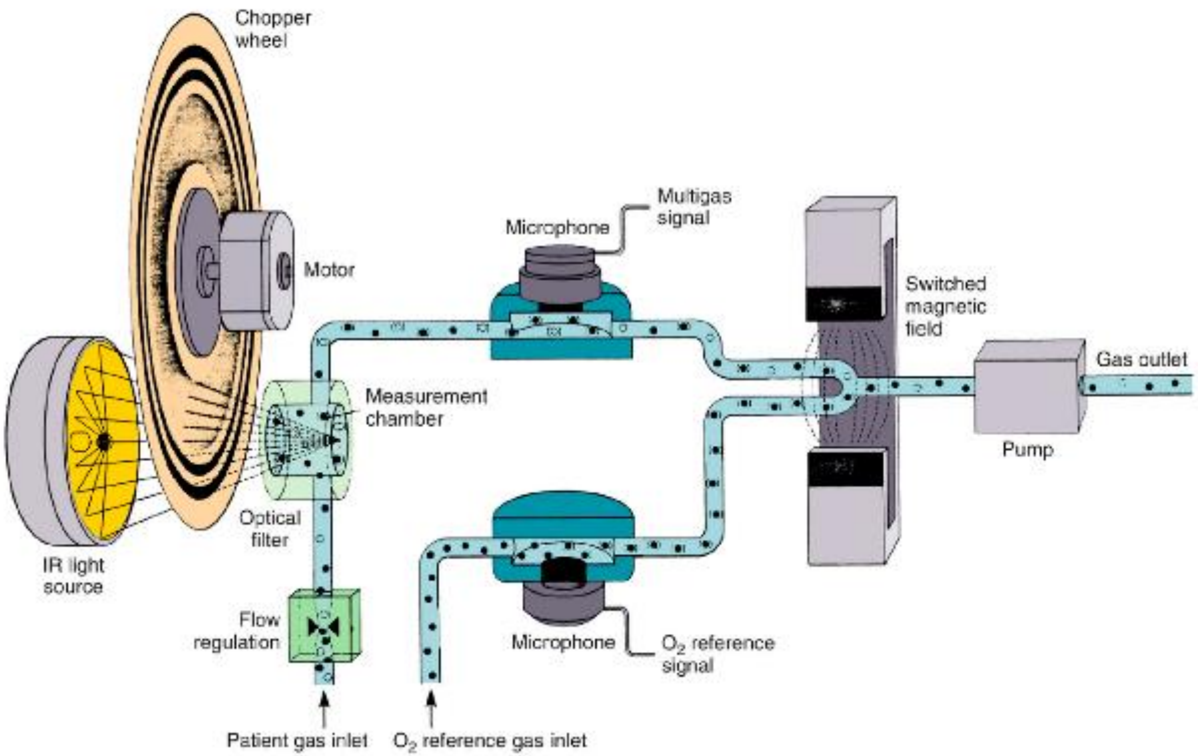


An infrared analyzer with multiple filters on a spinning chopper



Infrared Photoacoustic Spectrometer

- Each gas absorbs the pulsating IR energy in its absorption band, it expands and contracts at that frequency, and resulting sound waves are detected with a simple microphone.



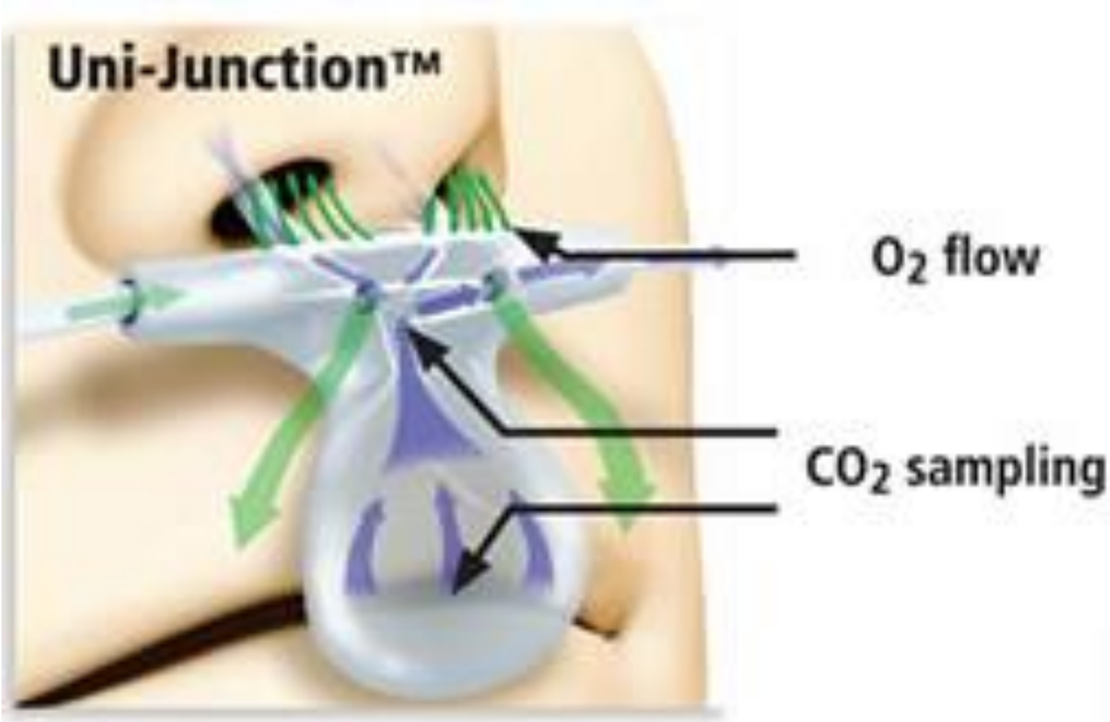
Phasain IRMA mainstream probe

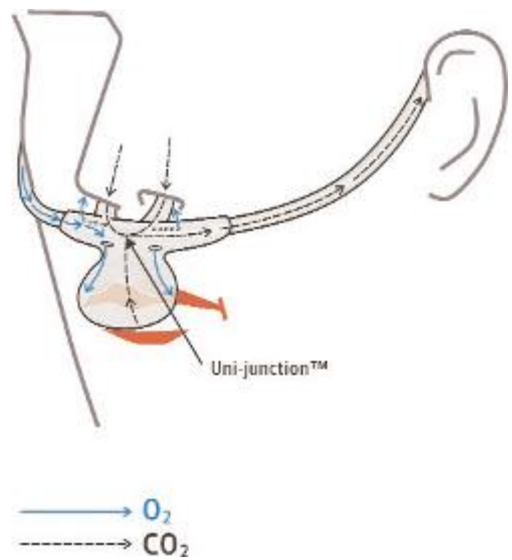
- Miniature, main stream
- 10 different wavelength
- Short answer time

Phasain EMMA CO_2 probe

- Capnometry
- Breathing frequency
- Alarms
- In any situation

Microstream. Neintubovaní pacienti





Comparison of analysers

Table 2: Technique, principle and limitations of anaesthetic gases analysers in anaesthesia machines		
Technique	**Principle**	**Remarks**
Infrared absorption spectroscopy	Analyses molecules having dissimilar atoms which absorbs infrared radiation	Alcohol, water vapour and carbon monoxide interfere with the absorption peaks of volatile agents. Phenomenon of 'collision broadening' seen with this technique
Photoacoustic spectroscopy	Similar to infrared absorption except that the initial radiation is pulsed and subsequent vibration pulse is detected using a microphone and then amplified	Same as above
Refractometry	Monochromatic light passes through the gas and is focused to have a patterned band which depends on the gaseous medium's refractive index and concentration	No breath-to-breath analysis. Calibrated for a particular gas. Useful tool to calibrate vapouriser output and detect environmental anaesthetic
Piezoelectric absorption	Resonance property is used for analysis	Unable to differentiate individual vapours
Raman scattering	Laser beam thrown on the gas in the chamber is scattered which is passed through a specific filter. The concentration of anaesthetic gas is proportional to the emitted photons through the specific filter	Fast response times. Analyze multiple anaesthetic agents with good accuracy
Mass spectrometry	The gas to be analyzed is ionised and separated, narrow band-filtered and detected by photo-voltaic receptors	Longer response time but is very accurate

Calibration of analysers

Technology	Gas						
	O_2	CO_2	N_2O	AA Specific	N_2	He	Ar
Mass spectrometry	X	X	X	X	X	X	X
Raman spectrometry	X	X	X	X	X		
Infrared light		X	X	X			
Infrared acoustic		X	X	X			
Fuel cell	X						
Paramagnetic	X						
Molecular correlation spectroscopy		X					
Laser diode absorption spectroscopy	X						

AA, anesthetic agent; *Ar*, argon; CO_2, carbon dioxide; *He*, helium; N_2, nitrogen; N_2O, nitrous oxide; O_2, oxygen.

Thank you for your attention