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# know your equipment... GAS MONITORS

Monitoring the respiratory gases and the inhalational anesthetic agents is an integral part of anesthetic management. This article is an attempt to explain the functioning and the construction of

concentration of oxygen. Most modern analyzers are constructed such that the channel of the sample gas and the reference gas is interposed with a pressure transducer that can detect minute changes in pressure. When a pulsed magnetic field is applied downstream, it attracts oxygen causing a fluctuation in pressure which is proportional to the amount of oxygen present. (Figure 2)

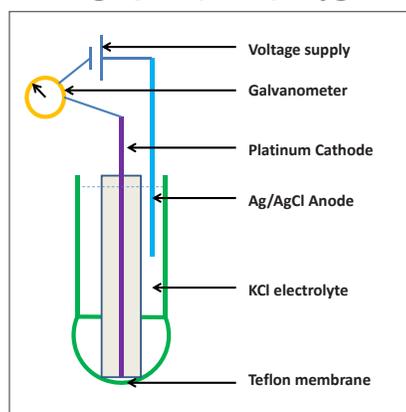
these monitors.

## Measurement of Oxygen

Oxygen ( $O_2$ ), by virtue of the unpaired electron in its outer orbit, has two important properties which are used to measure it.

1. It can accept another electron and therefore is an oxidizing agent and
2. It is attracted towards a magnetic field, or is 'paramagnetic'.

## Polarographic (Clark) Oxygen Electrode: (Figure 1)

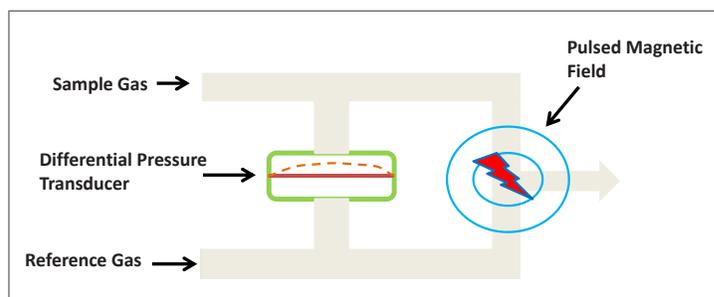


It consists of a platinum cathode and a silver/ silver chloride anode immersed in a KCl solution. When this is exposed to a sample of oxygen, it accepts electrons from the cathode while the anode provides the supply of electrons and thus generates a current. The current is

proportional to the amount of electron taken up, which in turn depends on the amount of oxygen. This principle is used to measure  $PO_2$  in arterial blood samples and also in a 'Fuel cell' used to measure the fraction of inspired  $O_2$  in some older anesthesia machines.

## Paramagnetic Oxygen Analyzer:

Oxygen is attracted towards a magnetic field and the force of attraction is proportional to the amount of oxygen molecules. The construction of the paramagnetic analyzers has changed over the years. The older version consisted of a dumb-bell shaped glass bulb filled with nitrogen suspended in a magnetic field. When oxygen containing gas was passed into the space it caused the dumb-bell to deflect due to its paramagnetic properties and the degree of deflection was proportional to the

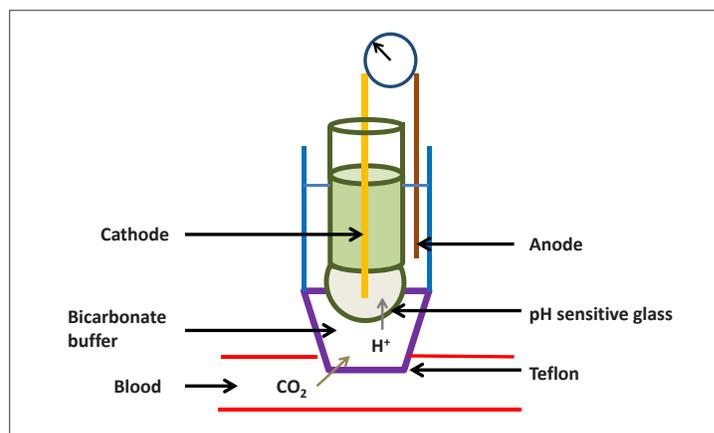


Most modern anesthesia workstations use paramagnetic oxygen analyzers to measure the percentage of oxygen in the breathing circuits.

## Measurement of Carbon dioxide

Carbon dioxide ( $CO_2$ ) reacts with water to produce  $H^+$  ions, which can be measured using a 'glass or pH electrode'. This is the basis of measuring  $PCO_2$  in blood samples by Severinghaus electrode. Measurement of  $CO_2$  in the gaseous phase is based on infrared absorption spectroscopy.

## $CO_2$ (Severinghaus) Electrode: (Figure 3)



The  $CO_2$  electrode is a modified pH electrode that works on the principle that an electrical potential across a glass membrane is proportional to the pH difference across it. The blood is separated from a buffer (bicarbonate) by a Teflon membrane.  $CO_2$  diffuses across this and reacts with the buffer to form  $H^+$ , which in turn crosses the  $H^+$  sensitive glass and reacts with the reference electrode to



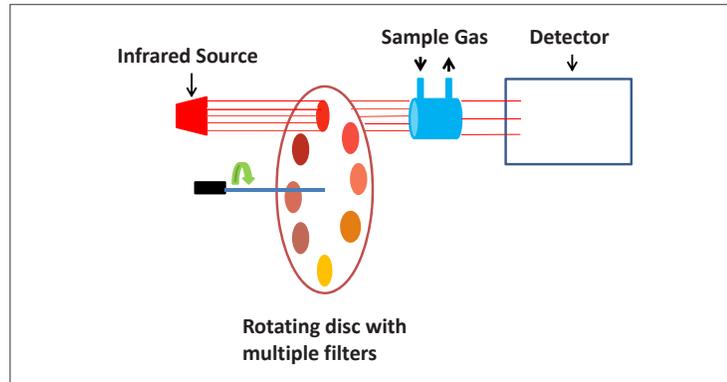
generate a current. The amount of current is proportional to the  $H^+$  produced which depends on  $PCO_2$  in the blood.

### Infrared (IR) Absorption Spectroscopy

Gases with two or more dissimilar atoms, such as  $CO_2$  and the inhalational anesthetics absorb infrared radiation (IR) and each gas absorbs a specific spectrum of IR. The specific absorption spectrum is  $4.3\mu m$  for  $CO_2$ ,  $4.5\mu m$  for nitrous oxide ( $N_2O$ ), and for halogenated anesthetic agents there are two peaks at  $3.3\mu m$  and  $7-13\mu m$ .

According to *Beer-Lambert Law*, the amount of light absorbed by a substance is directly proportional to the concentration of the molecules that absorb it and the distance the radiation travels within the medium. Since the amount of infrared radiation absorbed would be proportional to the concentration of the gas, this can be calculated by measuring the amount of radiation transmitted through the sample of gas. This method *cannot* be used to measure the concentration of gases with similar atoms such as oxygen, helium, xenon, argon and nitrogen, as these gases do not absorb infrared light.

#### Construction (Figure 4)



A source emits a broad-spectrum IR radiation which passes through a rotating disc with multiple filters that allows a particular wavelength to be transmitted. This filtered light of specific wavelength is then passed through the sample of gas in the measuring chamber before reaching an IR detector. Depending on the wavelength of the IR that is transmitted and the amount that is absorbed, the identity and the concentration of the gas is calculated.

The sample of gas from the breathing circuit is aspirated through a narrow sampling tube attached to the junction of the definitive airway or the mask and the breathing circuit. This system is called the 'Side-stream' as opposed to the 'Main-stream' type, wherein a sampling chamber is incorporated into the breathing circuit and the IR analyzer is wrapped around it and measures the gas concentration directly in the breathing circuit. Currently, most gas

analyzers in clinical use are the 'side-stream' type, and the volume of gas aspirated is 150-250 ml/minute. This volume of gas then passes through the paramagnetic analyzer to measure the oxygen concentration and is finally discarded into the scavenging circuit.

Two important points:

- The rapidly rotating disc with filters will allow IR of different wavelengths to be transmitted to identify the different gases in the mixture.
- Gas is continuously aspirated from the anesthetic circuit and delivered to the measuring chamber and since the response time of the analyzer is about 50-300 milliseconds, it is adequate to display a real time waveform of the concentration of different gases, during inspiration and expiration.

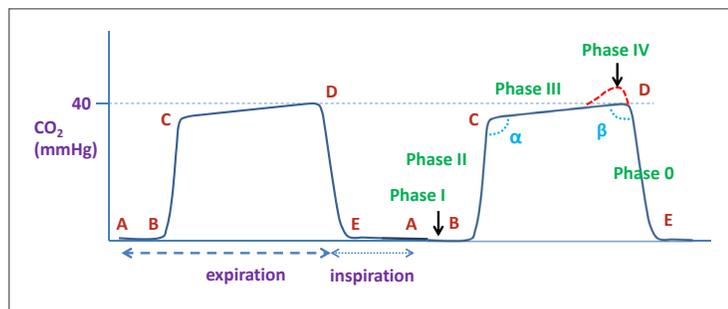
#### Errors in measurement

- The IR absorption spectrums of  $CO_2$  and  $N_2O$  overlap ( $4-5\mu m$ ) and this can interfere in the measurement of  $CO_2$  (*Cross Interference*). This can be reduced by using a narrow band width of IR specific for  $CO_2$  ( $4.26\mu m$ ).
- The gas mixture within the breathing circuit contains higher concentration of oxygen and nitrogen compared to  $CO_2$ , but these do not absorb IR. However, these gases collide with molecules of  $CO_2$  and increase or 'broaden' their absorption spectrum (*Collision Broadening*). This error is compensated by software computation of the amount of other gases present in the mixture.
- The gas aspirated from the breathing circuit is saturated with water vapor at  $37^\circ C$ , and it condenses by the time it reaches the analyzer. Water in the measuring chamber can interfere with the measurement. Therefore, the side-stream monitors have a 'water trap' to eliminate the water before the gas enters the measuring chamber.
- The presence of hydro-fluoro-alkane which is used as aerosol propellant can interfere with measurement of inhaled anesthetics. Therefore, when albuterol aerosol is being administered into the breathing circuit, it is prudent to detach the gas aspiration tubing from the circuit.

#### Capnography

The capnogram is a real time graphic representation of the amount of  $CO_2$  during inspiration and expiration. It provides useful information about the  $CO_2$  production, the pulmonary circulation, the alveolar ventilation, the pattern of ventilation and the integrity of the breathing circuit.

The capnogram has four phases and two angles. **(Figure 5)**

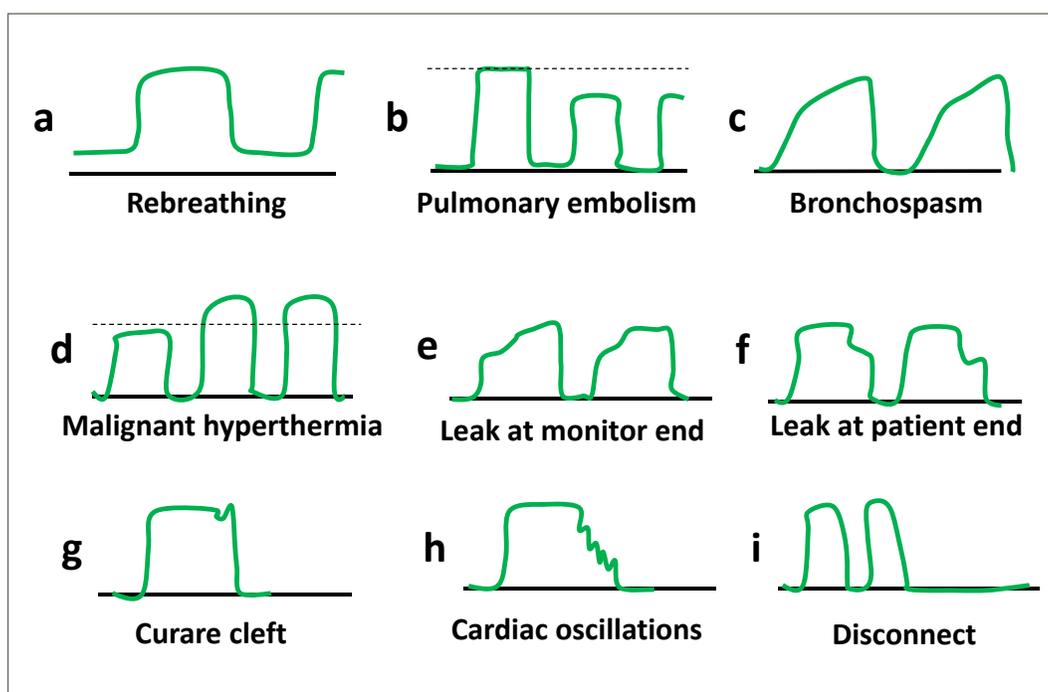


The phase I represents the inspiratory pause (E-A) and initiation of expiration (A). CO<sub>2</sub> is not detected during this phase as it represents the gas from the physiological and equipment dead space. The phase II (B-C) represents the transition between the dead space and the alveolar gas. The phase III (C-D) represents the gas from the alveoli and it has a gentle upward slope due to the variable rates of emptying of the different alveoli. The end of Phase III (D) represents the highest exhaled CO<sub>2</sub> and is displayed as the 'End-Tidal CO<sub>2</sub>'. Phase 0 (D-E) represents the initiation of the inspiratory phase and the CO<sub>2</sub> level drops to zero and is maintained such during the inspiratory pause (E-A). The α-angle between phase II and III is about 100-110°, but may increase with airway obstruction. The β-angle between phase III and 0 is about 90°.

During prolonged expiration or in patients with reduced thoracic compliance, the lung volume may fall below the closing volume and a slight upswing of the exhaled CO<sub>2</sub> at the terminal end of phase III, may be seen. This is labelled as phase IV.

Clinically important information can be interpreted from the capnography. **(Figure 6)**

1. If Phase I is higher than zero it indicates 'rebreathing' (exhausted soda lime, malfunctioning unidirectional valve or using a Mapleson's circuits with inadequate fresh gas flow). **(Figure 6a)**
2. A sudden reduction in ETCO<sub>2</sub> could suggest decrease in cardiac output, hypotension or pulmonary embolism. **(Figure 6b)**
3. A sloping Phase II indicates a slow exhalation (bronchospasm, COPD, kinked or obstructed endotracheal tube). **(Figure 6c)**
4. An increasing ETCO<sub>2</sub> could suggest increased CO<sub>2</sub> production (malignant hyperthermia, shivering), increasing CO<sub>2</sub> load (pneumoperitoneum during laparoscopy, rapid bicarbonate infusion, release of limb tourniquet), or improved cardiac output or return of spontaneous circulation during cardio-pulmonary resuscitation. **(Figure 6d)**
5. A 'step' in the capnography tracing
6. A step from phase II to III could indicate a leak in the sampling tube at the monitor end because the sample is diluted by the aspiration of ambient air. This picture may also be seen in patients with single lung transplant where the improved transplanted lung would expel more CO<sub>2</sub> for a longer time. **(Figure 6e)**
7. A step from phase III to phase 0 could suggest a leak in the sampling tube at the patient end. Initial exhalation has rapid flow and it feeds the sample line but later as the flow decreases ambient air would be aspirated and dilute the CO<sub>2</sub>. **(Figure 6f)**
8. A slight dip near the end of the phase III could indicate an inspiratory effort by the patient and it is commonly known as 'Curare cleft', indicating wearing off of the muscle relaxant. It could also suggest physical pressure on to the diaphragm or chest wall



by the surgeon or assistant! (Figure 6g)

9. Cardiac activity may manifest as oscillations during phase 0. (Figure 6h)
10. A sudden absence of the capnography trace usually indicates a disconnection of the anesthetic circuit or a blocked sampling tube, which is commonly due to condensed water vapor. It could also indicate a cardiac arrest. (Figure 6i)

### **Measurement of Inhalational Anesthetic agents**

Although, the IR absorption technique is commonly used in most modern anesthesia workstations, other methods such as mass spectrometry, Raman scattering, gas chromatography and quartz crystal adsorption can be used to measure inhalational anesthetic gases.

#### **Infrared absorption spectroscopy**

Since the absorption spectrum of the commonly used inhalational anesthetic agents is similar at 3.3 $\mu$ m wavelength of IR radiation, the agent being used needs to be acknowledged. However, if a polychromatic IR radiation of 7-13 $\mu$ m is used, then the monitor can automatically detect the anesthetic agent used because, at these wavelengths, the absorption spectrum is relatively different for the various agents.

#### **Mass Spectrometry**

Mass spectrometry measures the concentration of gases based on their mass or molecular weight. A gas sample is aspirated into a high vacuum chamber and ionized using a beam of electrons. The ions are then accelerated by an electric field into a chamber that has a strong magnetic field perpendicular to the path of the ionized gas. The ions are deflected by this magnetic field proportional to their charge and inversely proportional to their mass and measured by a photodetector. The angle of deflection and the ion flux can be used to identify the gas.

Mass spectrometers are accurate, quick and require a small sample. However, these are expensive and bulky and usually used for research or to analyze gas samples from several patients at different locations.

#### **Raman Spectroscopy**

When a light beam strikes a gas molecule the photons are scattered with intensity less than the incident light but retain their wavelength. This is known as Rayleigh scattering. However, some molecules can absorb part of the energy of the incident light and emit photons of a different wavelength which is unique to the gas. This phenomenon was described by Raman in 1928. The quantity of Raman scattering gives a measure of the concentration of the gas present. The incident light used for this technique of gas measurement is argon laser, making this equipment expensive and bulky.

#### **Gas Chromatography**

If the different gases in a mixture can be separated, then it can be identified and measured. A gas mixture can be separated by a technique of chromatography, which literally means 'writing in color'. The apparatus consists of passing a stream of inert gas such as

nitrogen or argon (the mobile phase) through a long tube packed with silica-alumina beads coated with polyethylene glycol (the stationary phase). The gas mixture to be measured is injected into the mobile phase. Depending on the differential solubility of the different gases in the two phases, the time taken for each gas to reach the other end of the tube varies. The concentration of each gas component is measured at the outlet using one of three techniques – thermal conductivity, flame ionization or electron capture. Although the gas chromatography is very versatile and can measure all the gases in the anesthetic circuit accurately, it does not allow continuous measurement.

#### **Quartz crystal adsorption**

A quartz crystal resonates when a potential is applied to it and this is known as 'piezoelectric' effect. When a quartz crystal coated with a thin layer of oil is exposed to the gas from the breathing circuit, the anesthetic vapor dissolves in the oil film and changes the resonant frequency of the vibrating crystal. The shift in frequency is related to the amount of vapor dissolved in the oil and can thus be measured. The drawback of this monitor is that it cannot differentiate the different vapors and has to be calibrated for the agent being used.

The information obtained by monitoring the respiratory gases and the anesthetic agents is indispensable to ensure patient safety during the perioperative period. As anesthesiologists, it is imperative that we have a good understanding of the physical principles, usefulness and limitations of this equipment. ■

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