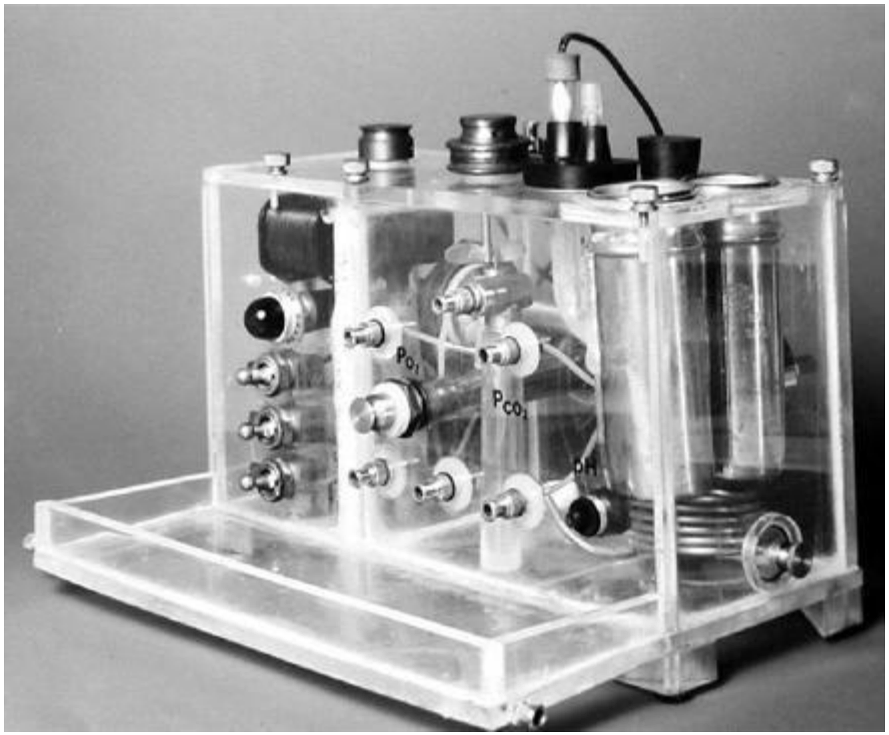
Blood Gas Electrodes

Bhagya Gunetilleke



The first three function blood gas analyzer

Modern blood gas analyzer

Outline

- Principles of measuring pH, pCO2, pO2
- Calibration & sources of error
- Continuous blood gas analysis
- Co-oximeter & other newer develpoments

Blood Gas Analysis

- First clinical application of pH & pCO2 – During the polio epidemics, Copenhagen 1952
- Coincided with the first involvement of the ‘Anaesthetist’ in managing patients ‘out of theatre’

Blood Gas Analysis

- Physicians, guided by cyanosis, focused on providing O2, **Bjorn Ibsen-Anaesthetist**, postulated that inadequate ventilation &CO2 retention caused death in polio patients

- Intubation & positive pressure ventilation guided by blood pH measured using the pH electrode

- Modern intensive care was ‘conceived’ by Ibsen in Copenhagen 1952

Blood gas machine

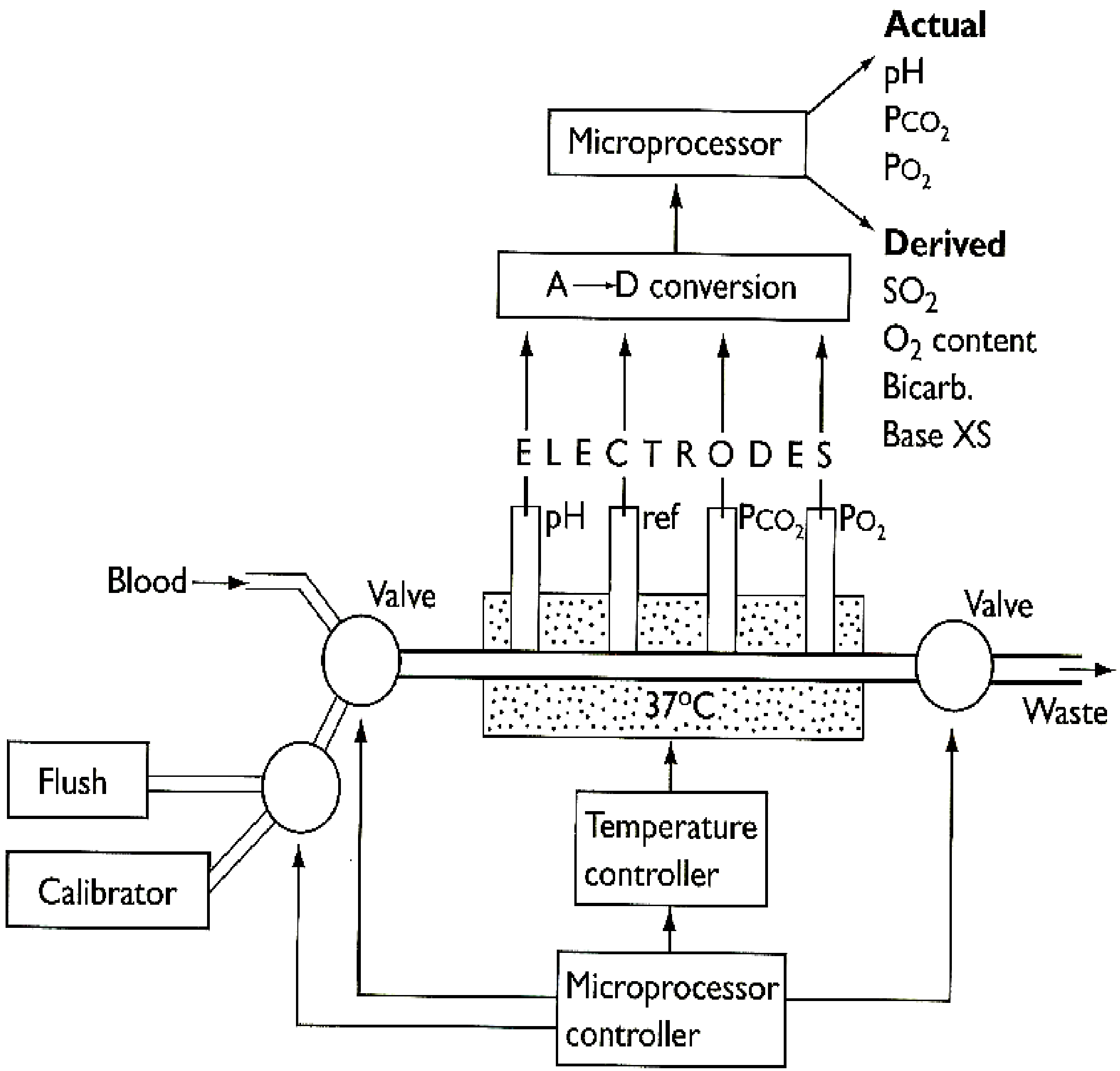


Figure 19.17 Blood gas analyser.

pH electrode: Working Principle

- When 2 solutions with different chemical activity (eg. pH) are place on either side of a semi-permeable membrane an electro motive force (emf) is generated. This can be quantified using a voltmeter
- The change in PH in one solution will result in a change in the voltage

pH electrode

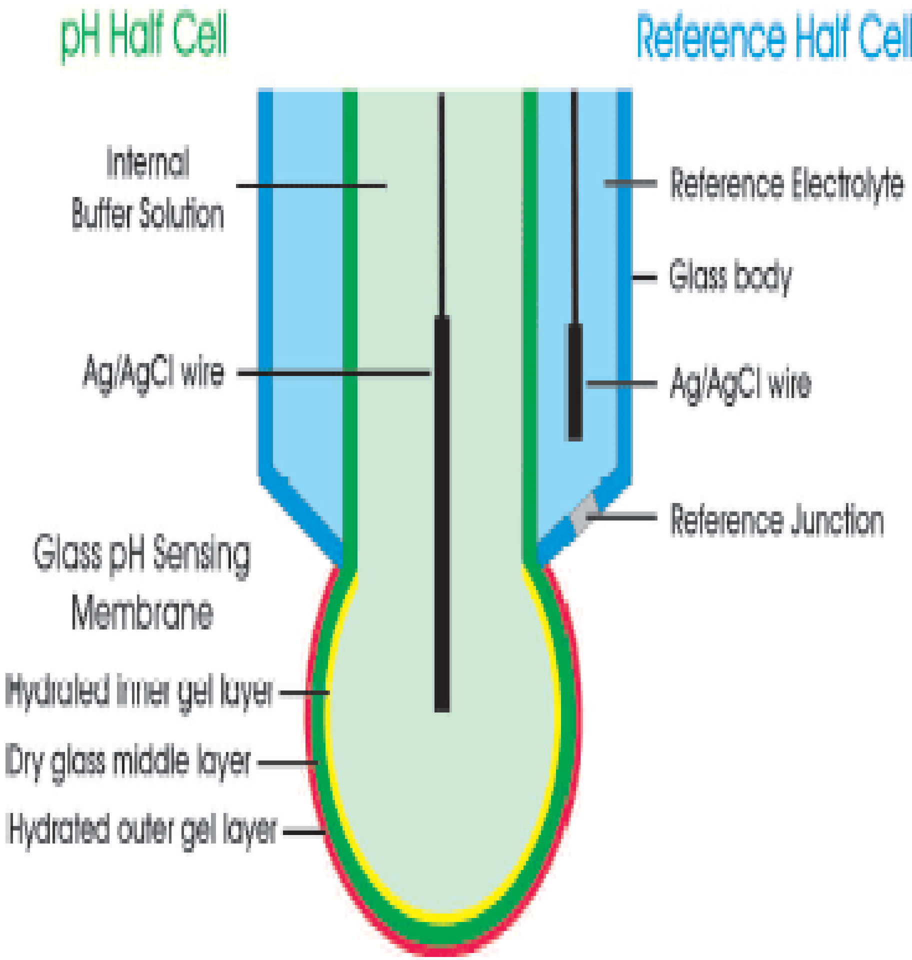


Figure 1 Typical combination pH electrode.

- Consists of 2 half cells.
  - Ag / AgCl (glass electrode)
  - Hg / Hg_2Cl_2 (calomel electrode)
- Glass electrode immersed in buffer (same p H as calibrating solution) so at constant pH, which is separated from the blood by a H^+sensitive(permeable) glass membrane.
- Calomel electrode separated from the sample by KCl bridge.

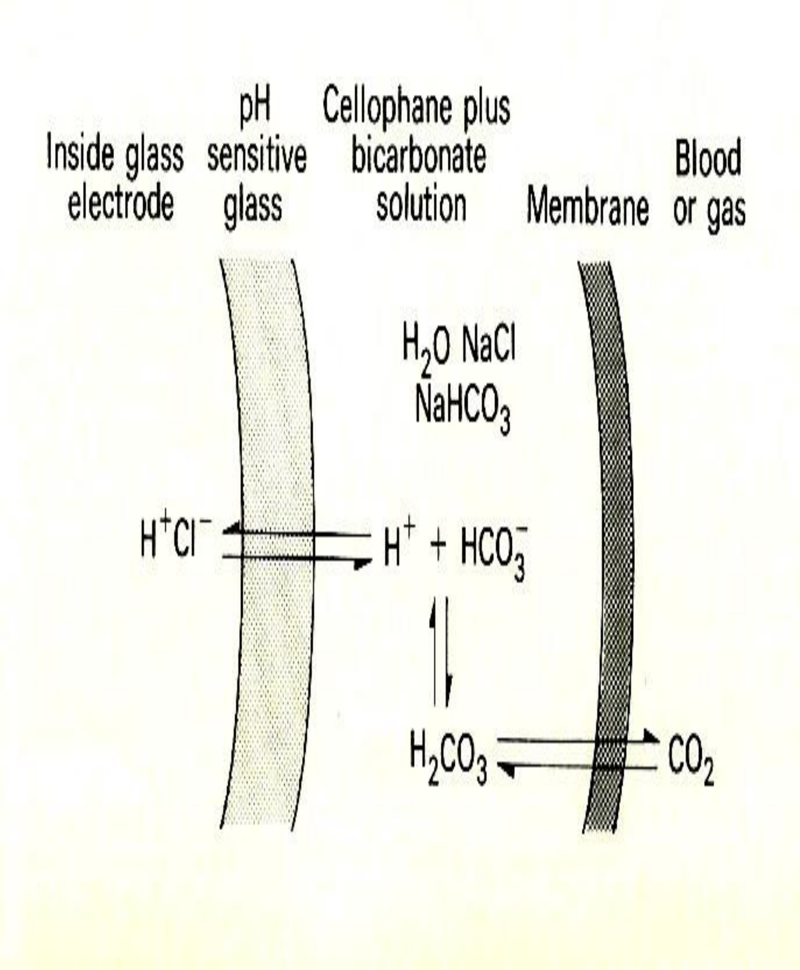
pH electrode

- H+ (not other +ve ions) moves through the glass selectively, completing the circuit
- When complete, an Electo Motive Force (emf) is created. It is proportional to the **activity** (not the concentration) of the H^+
- pH change of 1 produces 60 mv change
- The pH of the buffer solution is taken as the base line pH

Stow-Severinghaus CO_2 Electrode

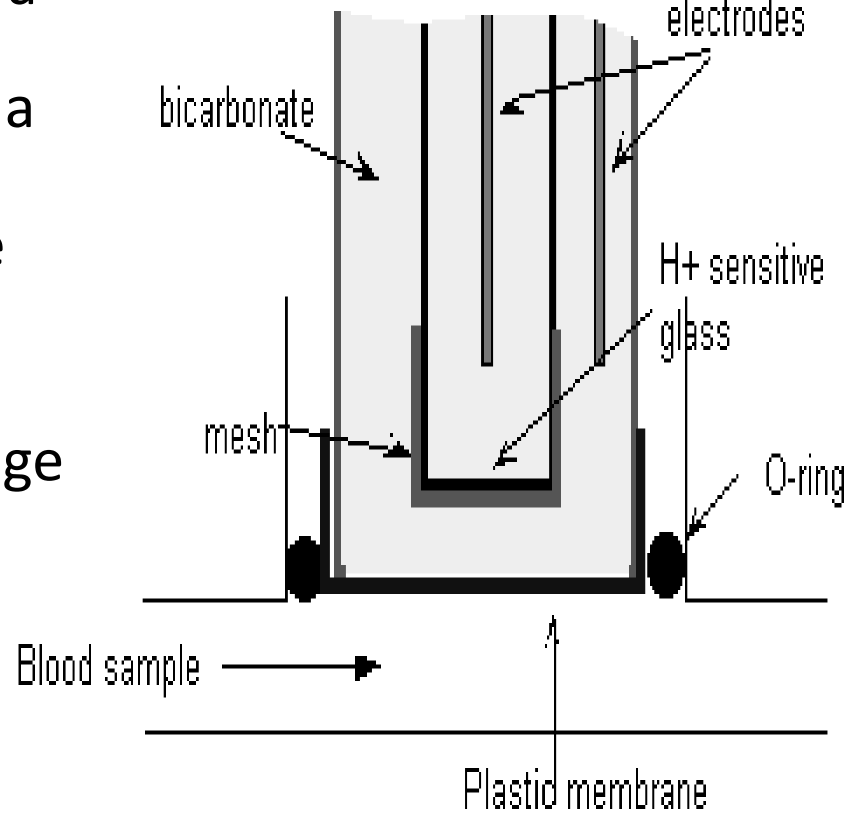
- Invented by R.W.Stow
- Rubber glove around PH glass & reference electrode
- CO_2 diffused through rubber & reduced PH of water film
- Calibrated using CO_2 mixtures of known concentration but drift significant

  Further improvements: Severinghaus
- Film of HCO3- to replace H2O reduced drift & improved sensitivity



Stow-Severinghaus CO_2 Electrode

- H+ sensitive glass with electrode enclosed within.
- Sample separated from glass by a nylon / teflon membrane selectively permeable to CO_2 & a thin layer of H2O/$NaHCO_3$
  - $NaHCO_3$ stablizes the electrode
  - CO_2 combines with H2O to give rise to HCO_3 - & H+
  - Glass electrode measures change in [H+]
  - Change of 1.25 mmHg causes 0.01 p H change.



Polarographic / Clark O_2 electrode

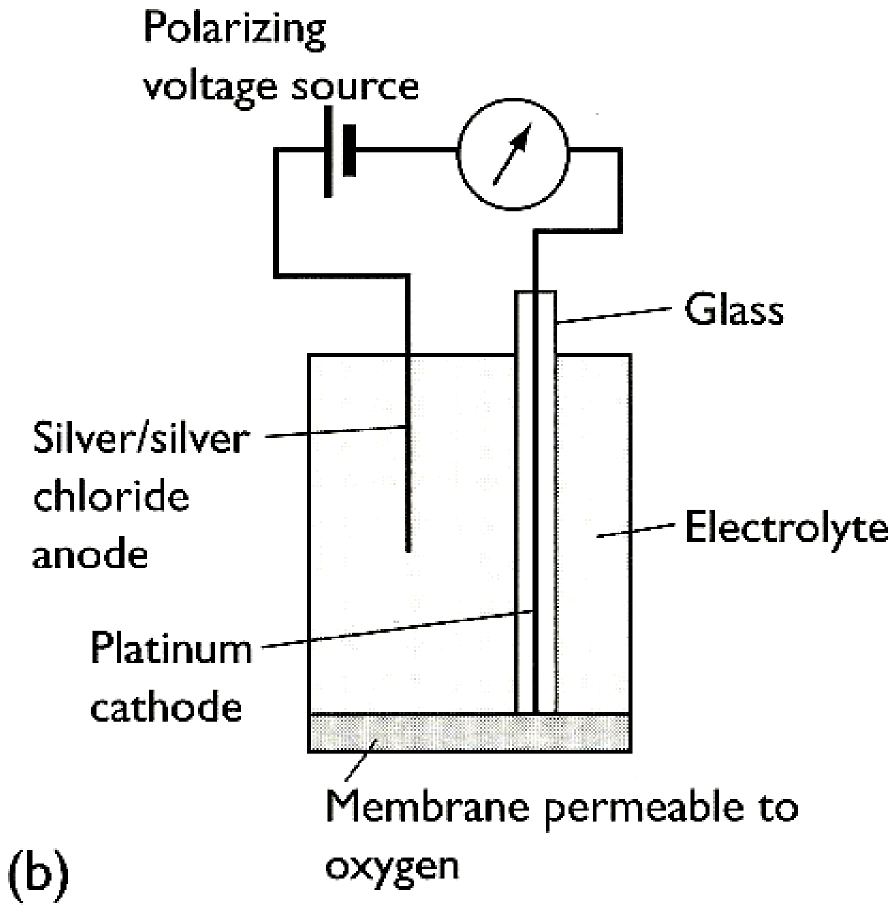


Figure 19.1 Working principles of (a) a galvanic oxygen fuel cell and (b) a polarographic oxygen analyser.

Polarographic/Clark O_2 electrode

- Ag/AgCl anode and Pt cathode immersed in a KCl solution.
- Separated from the blood by a polyethylene (fast) or polypropylene (stable) membrane, through which O_2 can diffuse.
- Polarizing voltage of 600mv.
- Anode
  - $4\ Ag \rightarrow 4\ Ag + 4\ e^-$
  - $4Ag^+ + 4\ Cl \rightarrow 4\ AgCl$
- Cathode,
  - $O_2 + 2\ e + H_2O \rightarrow 4\ (\ OH^-\ )$

Polarographic/Clark O_2 electrode

- Concentrations of O_2 (0 % & 12 %) for calibration
- Availability of electrons depends on the concentration of O_2
- The current generated is proportional to the O_2 concentration at Pt electrode.
- Only 10^{-11} A / mmHg
- Current generated is too small to be measured by an ammeter. Wheastone bridge circuit for measurement
- Electrode maintained at 37oC

Calibration

pH electrode

Two buffer solutions with a known p H (p H 6.841 & 7.383)

pCO2 electrode

CO_2 canisters are incorporated.

Canister gas mixes with room air to provide 2 known concentrations.(5.61% & 11.22 %)

Gases are fully humidified before calibration.

$p\ CO_2 = \underline{CO_2\ \text{conc. X (B.P. – SVP)/100}}$

pO2 electrode

De-ionized water saturated with 100% O2 and 0% O2

Two-Point Calibration

- E.g.. for pH electrode

  Measure the response of the electrode to 2 solutions with known pH & create a linear graph

  'Offset' - mV reading at pH 7

  'Slope' – change in mV per unit change in unit change in pH

  (Ideally 59.16mV/pH at 25OC)

Sources of error –O_2 Electrode

- Relationship between O_2 concentration & the current generated becomes non-linear at high O_2 concentrations. Degree of error depends on

  Cathode diameter

  Voltage applied

  Membrane type (Life span of Teflon membrane – 3yrs)
- Consumption of O_2 by the electrode

  2 – 6 % drop from the actual value

  More with large cathodes

  – Falsely high reading with Halothane

Common Errors

- Systematic errors
  - Electrode performance
    - Membrane deposits
  - Calibration errors
    - Expired / contaminated reagents
  - Membrane integrity errors
    - Holes / cracks
- Temperature
  - If the patient's T^0 not 37^0 C, a correction is needed.

Sampling errors

- Incorrect collection
  - Heparin
    - Dilutes the sample
    - Reduces the p H
- Gas bubbles
  - In theory, lowers the pCO_2 & changes the pO_2.
  - Does not interfere with the results if used immediately as equilibration takes a long time.

Storage errors

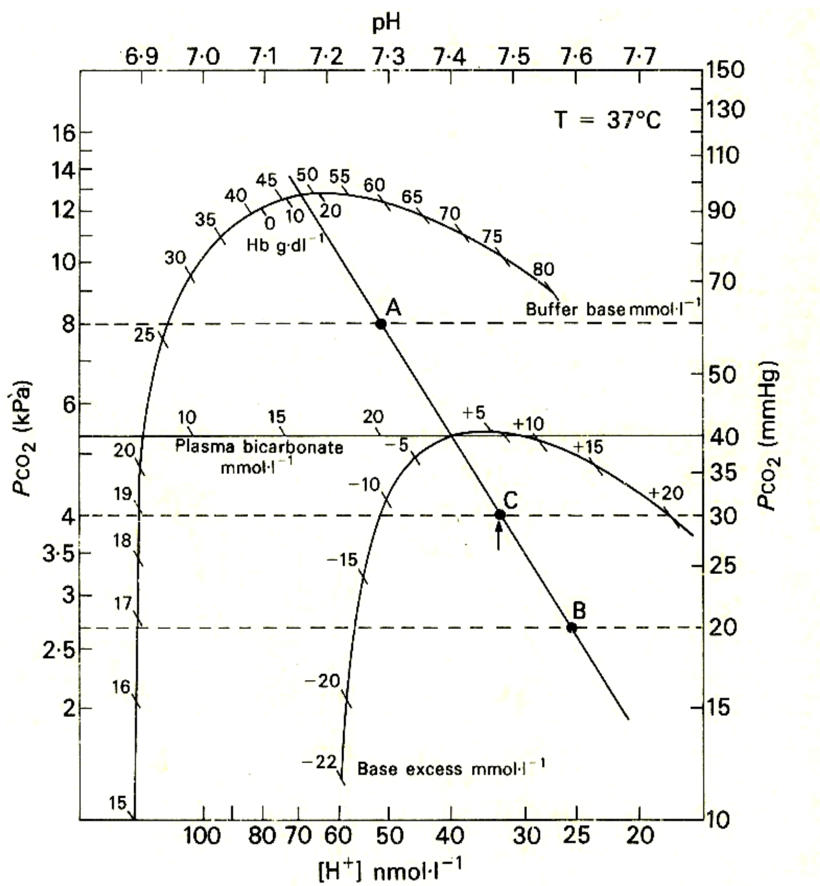
- High WBC
  - increases p CO_2 & decreases p O_2 due to aerobic metabolism.
  - No significant effect if the count is below 20,000.
- Air bubbles / leaky syringes
  - Can alter results after 20 – 30 min.
  - **gases are more soluble at low temperatures.**

Calculated Values

- Standard Bicarbonate & Base excess quantify the metabolic component of the acid-base disturbance
- Standard HCO_3 (Jorgensen & Astrup)
  - Bicarbonate concentration in plasma under standard conditions i.e.. Equilibrated with gas having pCO_2 of 40 mmHg, saturated with O_2 at 37^0C.
- Base excess (Astrup & Siggard-Andersen)

  Amount of a strong acid / base required to titrate a liter of blood back to a pH of 7.4 at a p CO_2 of 40 mmHg, saturated with O_2 at 37^0C.

Siggard – Anderson normogram



- Earlier used to check p CO_2. (Astrup interpolation)
- Std. HCO_3, BE & total buffer base could be read directly from this chart.

Actual HCO_3

(HCO_3)mmol/l = a.p CO_2 X $10^{(pH-6.1)}$

^{a} =0.231 for kpa or 0.0301 for mmHg

Intravascular electrodes

- All 3 electrodes are available for intravascular use.
- They are miniature forms of these electrodes mounted on a catheter tip.
- Difficult to insert & calibrate.
- Deposition of fibrin is a major problem.
- Fast response time.

Transcutaneous electrodes

- Miniature O_2 & CO_2 are incorporated in to a finger probe, which also has a heating element & a contact liquid.
- The probe forms an air tight seal in the finger.
- The unit is heated to 43^0C to dilate blood vessels.
- Gases diffuse through the skin.

Disadvantages

- No pH monitoring.
- Values are lower
  - Decreased solubility
- Diathermy interference
- Low values in shock & hypotension.
- Burns

Advantages

- Non-invasive
- Very useful in neonatal monitoring

Fluorescence based analysis

- A fibre-optic probe with a sensor at the tip.
- Placed intravascularly via a 20 G cannula.
- Uses light from pulsed Xenon lamp with wave lengths of 410nm(p H), 460nm(Pco_2) and 385nm($p\ O_2$).

p H measurement

- Weak, fluorescence acid at the sensor tip.
- Dissociates according to the p H.
- 410nm excites the dissociated form & 460nm excites the non-dissociated form.

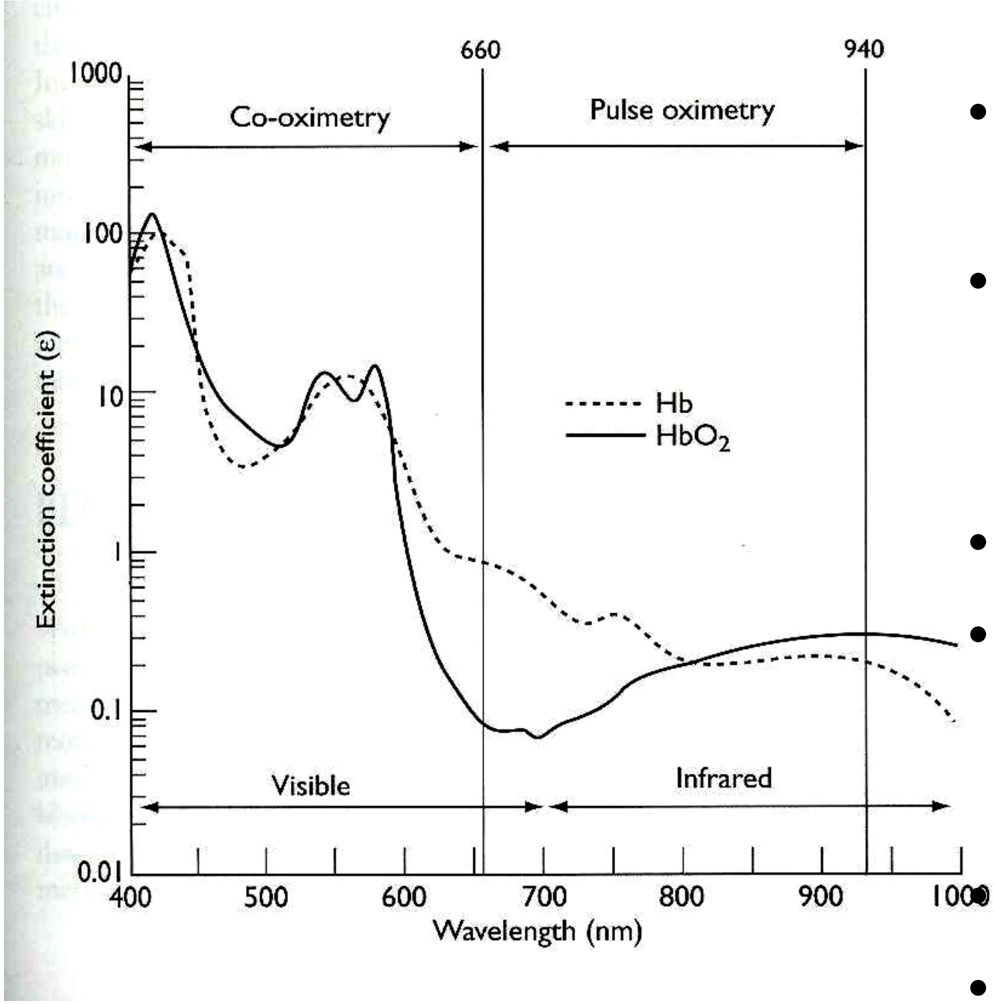
CO_2 measurement

- A buffer encapsulated with a silicone membrane is allowed to equilibrate with blood CO_2.
- This is excited at 460nm.

0_2 measurement

- An 0_2 absorbing dye is encapsulated with a silicone membrane.
- This is excited at 385nm.

Co-oximeter



- Newer machines do co-oximetry.
- It only measures the 0_2saturation;

not partial pressure.

- Spectrophotometry principle
- Uses multiple wave lengths (visible)

on a haemolysed sample

- Can **measure** saturation, Hb,
- O_2 content, metHb, COHb etc.

Recent Developments

- Additional Parameters

  Ion selective electrodes are incorporated to the machine to measure Na,K,Ca,Cl, Li

  Hb, PCV

  Lactate, Glucose
- Single integrated gas & liquid calibration cartridge
- Single quality control cartridge
- Small sample volume (125micl)
- Rapid results (Less than 1 minute)

Acknowledgements

- Severinghaus J. First electrodes for blood PO_2 and PCO_2 determination *J Appl Physiol* 97: 1599-1600, 2004
- Ward's Anaesthetic Equipment 4th Edition
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- John W. Severinghaus, Poul Astrup, John F. Murray. Blood Gas Analysis and Critical Care Medicine Am. J. Respir. Crit. Care Med., Volume 157, Number 4, April 1998, S114-S122
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