By Adam Hollingworth

Measurement

SI Units

- basic SI units:

- Mass - **kg**
- Length - **m**
- Temp - **K**
- Current - **Amp**
- Luminous intensity - **Cd** (candela)
- Time - **s**
- Amount - **mol**

Derived units:

- Temp in celcius (degree C = K - 273,15)
- Force = Newton (N) = $kg.m.s^{-2}$
- Pressure = $N.m^{-2}$ = Pascal (Pa) (1 Bar = 1 atmosphere = 101,3 kPa)
- Energy = Joule (J) = N.m
- Power = watt = $J.s^{-1}$
- Frequency = Hertz (Hz) = s^{-1}
- Volume = m^3 (= the official SI unit, liter is not an SI unit.)

Electrical units:

- Potential (volt): V = $W. A^{-1}$
- Resistance (Ohm): R = $V. A^{-1}$
- Charge (Coulomb); C = A.s (1 C = electrical charge of 6,24 x 10^{18} electrons)
- Capacitance (Farad): F = $C. V^{-1}$

Miscellaneous:

Pico = 10^{-12}
Nano = 10^{-9}
Micro = 10^{-6}
Milli = 10^{-3}
Kilo = 10^{3}
Mega = 10^{6}
Giga = 10^{9}

Standard Temperature and Pressure (STP): = 273,15 K and 101,3 kPa

Gas Laws

1. **Boyle's law:** (the 1st perfect gas-law)

At a constant temperature, the **volume** of a gas is inversely proportional with the absolute **pressure**.
[Note: Boyle's law is applied in the Body plethysmograph… loved by registrars + examiners…]

$$V = \frac{1}{P}$$

Thus, $V.P = k_1$

2. **Charles law**: (second perfect gas law)

At constant pressure, the **volume** of given gas is directly proportional to the absolute **temperature**.

$V = T$

Thus , $V/T = k_2$

3. **Third perfect gas-law**:

At a constant volume, the **pressure** of a given mass of gas varies directly with absolute **temperature**.

$P = T$

Thus, $P/T = k_3$

4. **Dalton's law of partial pressures:**

In a *mixture* of gases, the pressure exerted by each gas is the same as that which it would exert if it occupied the container *alone*.

Note: by applying Boyle's law + Dalton's law, the partial pressure of a gas in a mixture is obtained by multiplying the total pressure with the fractional concentration of the gas.

Miscellaneous:

Law of Mass action: ***Rate*** *of chemical reaction = proportional to the* ***produc****t of the concentrations of reactants.*

5. **Avogadro's hypothesis:**

Equal volumes of gases, at same temp + pressure, contain the same amount of molecules.

6. **Avogadro's number:** = $6{,}022 \times 10^{23}$ = number of atoms in 12g Carbon 12 = ONE MOLE.

7. **Mole:** = the quantity of substance containing the same amount of particles or molecules as there are atoms in 12 g of carbon (C_{12}).

8. **OsMole:** = number of moles of a solute which contribute to the osmotic pressure of a solution

   Note also: *one mole of any gas at STP occupies a volume of* **22,4** *liter.*

9. **Universal Gas constant (R):**

From P.V = k_1 , V/T = k_2 , P/T = k_3 : → **PV/T = K**

For 1 mole of gas, PV/T = R (R = universal gas constant)

→ **PV = nRT** (where n = number of moles of the substance)

in practice P = directly proportional to n (V,R + T kept constant)

9. **Critical temperature:**

That temperature, **above** which a substance cannot be liquefied, no matter how much pressure is applied.
↳ ie becomes a gas

- Critical Pressure: = vapour pressure of a substance at its critical temp.
- Lines of pressure against volume at various temp's = isotherms
- The term "**Gas**" applies to a substance above its critical temp
- Term "**vapour**", to a substance below its critical temp.
- "Filling ratio" of a cylinder: = mass of gas in the cylinder divided by mass of H2O which would fill it (~ internal volume of cylinder) = used to describe how much gas is used to fill a cylinder.

10. **Pseudo-critical temperature:**

In a *mixture* of gases, there is a specific critical temperature at which the mixture may *separate out into its constituents*. (Poynter Effect)

- Eg, **Entonox** (50% O2 + 50% N2O) = dependant on pressure + temperature.
  - Below –7 Celcius at 137 Bar ⇒ liquefaction of N2O with gaseous O2 at top ⇒ consumed 1st ⇒ pure N2O hypoxic mixture to follow
  - ∴ Entonox cylinders must always be stored above –7 degrees.

11. Henry's law

At a given temp, the amount of a given gas dissolved in a given liquid, is directly proportional to the partial pressure of the gas in equilibrium with the liquid.
Eg: dissolved oxygen in blood (mlO_2/100ml blood) = 0.003 x PO_2

Note: At *equilibrium*, the tension of the dissolved gas is the same as the partial pressure of the gas above the surface of the liquid.

Other factors influencing the solubility of gases in liquids:

- **Temperature:** The higher the temp, the *less* soluble gases get in it. (Reason for bubbles in boiling water and bubble-formation in a heated ivi line)
- **Type of gas:** Different gases has different solubilities (eg N2O > N2)
- **Type of liquid:** eg water vs blood (eg N2O has higher sol in blood vs H2O)

12. Ostwald Solubility coeffiecient:

The volume of gas that dissolves in one unit volume of liquid at a given temperature.

Note: = independent of pressure

13. **<u>Partition coefficient</u>:**

The ratio of the amount of substance present in one phase compared with another, the two phases of equal volume and in equilibrium.

eg blood:gas coefficient N2O 0.47 = 1ml blood contains 0.47 of the alveolar conc of gas @ 37deg

= similar to Ostwald, but:

a. Relative order of phases must be specified, eg blood:gas
b. Can be applied to two liquids (eg blood:oil)

Note:
- At equilibrium, the ***tension*** of the gas in the two liquid phases must be equal.
- <u>Tension</u> is used instead of *partial pressure* for gases in solution.
- ∴ the tension of a gas in solution = the partial pressure of the gas which is in equilibrium with it.

Solubility + uptake of anaesthetics:

- The higher the Ostwald solubility, the more gas carried away by blood and the slower the build up of [ ] in the alveoli.
- The [ ] of anaesthetic in blood + brain are close to the alveolar concentration, → thus, faster onset with a less soluble agent eg desflurane.

Note: solubility is very relative, eg N2O has low solubility c/f say sevoflurane, but high solubility compared to eg N_2.
↳ solubility = 20x O2, 40x N2

Practical implications:

- Second gas effect: During induction of anaesthesia with N2O, at peak of inspiration, when alveolar pressure equalized with ambient pressure, there is a surplus of N2 + O2 (because of the more rapid uptake of N2O). = augmented alveolar flow. Conversely, [N2O] is increased in alveoli if given with halothane (more soluble).
- Diffusion hypoxia: = reverse of above, = faster excretion of N2O into alveoli dilutes gases present there, eg O2.

Oil solubility and anaesthetic potency:

The more oil soluble, the more potent, thus low MAC ~ high oil solubility.

Postulated reason: high oil-solubility ? related to affinity for long fatty acid chains within neurons / synapses in brain.
Attachment to FA chain molecules = relatively loose + readily reversible Van der Waals type bonds.

Pressure

Conversion of units for pressure:

SI unit = N/m^2 , and 1 N/m^2 = 1 Pa.
1 kPa ~ 7,5 mmHg
1 kPa ~ 10 cmH2O
1 kPa ~ 10^4 dyne.cm^2
1 Bar (1 atmosphere) = 101,3 kPa

Gauge vs absolute pressure:

- **Gauge** pressure: pressure above or below atmospheric pressure.
- **Absolute** pressure: gauge pressure + atmospheric pressure.

Eg:

- Gauge pressure of a full cylinder O2 reads 140 Bar (14 180 kPa) → t
- absolute pressure is 141 Bar (14 283 kPa)
  - ↳ ∴ the absolute pressure of an **empty** cylinder at sea level = 1 Bar (101.3 kPa)

Pressure Gauges

- classification:
  - liquid manometers
  - anaeroid gauges: bourdon, bellows
  - diaphragm type

Liquid Type

- water, alcohol, mercury
- principle:
  - pressure exerted by column of liquid depends on force of gravity on the mass of liquid in the column
  - mercury x13.6 more dense than water
  - meniscus:
    - water manometer - see concave meniscus: adhesive forces of water to glass > waters cohesive forces
    - mercury manometer - see convex meniscus: cohesive forces > adhesive force to glass
    - ↳ should take reading from centre of tube irrespective
  - capillarity:
    - adhesiveness of water ⟹ capillarity
    - dip tube into reservoir, water will draw itself up tube until gravity overcomes the adhesive forces
    - see opposite with mercury
    - result
      - water manometer will over-read by 4.5mm in 6mm diameter tube
      - mercury manometer will under-read by 1.5mm in 6mm tube
- example:
  - mercury sphygmanometer = end must be open to air because gauge pressure is measured
  - mercury barometer = end sealed

Anaeroid Gauges

- anaeroid = no liquid

- Bourdon gauge
  - = used for cylinder pressure
  - mechanism:
    - coiled tube:
      - one end connected to pressure source
      - other end closed
    - ↑pressure ⟹ tube to uncoil which moves pointer on a calibrated scale

Diaphragm

- pressure change ⟹ movement of flexible diaphragm
- movement sensed & transduced via:
  - wire strain gauge =
    - wire stretched or compressed ⟹ electrical resistance to change
    - usually incorporated into a wheatstone bridge
    - eg A line transducer
  - optical =
    - reflection of light off the moving diaphragm changes the amount detected by a photoelectric cell
    - eg some fibre optic cardiac catheters
  - capacitance =
    - diaphragm = one plate of capacitor
    - distance from other plate varies with movmt of diaphragm
  - inductance =
    - diaphragm attached to a magnet which is moved between coils as diaphragm bulges ⟹ potential proportionately

Wheatstone Bridge

- = special circuit used to measure changes in resistance
- usually coupled with a strain gauge
- it is used to ↑sensitivity/gain of a measuring circuit
- this is done by constantly reseting reference range to zero
- original form includes:
  - 4 resistors
  - battery - source of electrical potential
  - galvanometer

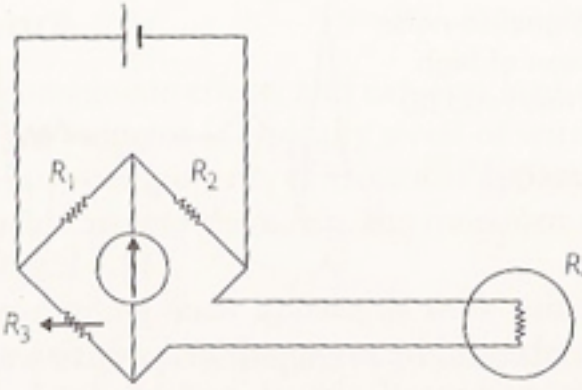


Figure 14.14 Wheatstone bridge circuit; R_4 is a strain gauge transducer or resistance thermometer and R_3 is a variable resistance which is adjusted until there is a null deflection on the galvanometer

- theoretical arrangement:
  - R4 = strain gauge transducer ie measuring resistor
  - R3 = variable resistor
    - this is changed by the circuit so that R1 + R2 = R3 + R4 ie zero

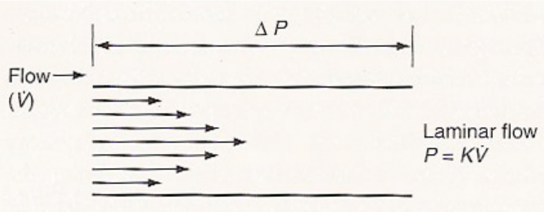
    - ∴ galvanometer in middle should read zero
    - = a null deflection system
  - this is how ↑sensitivity is created:
    - change of measurement from zero ⟹ 1 = 100%
    - change of measurement from 100 ⟹ 101 = only 1%
- practical arrangement:
  - pressure transducer contains 4 strain gauges which form 4 resistors in Wheatstone bridge:
  - 2 gauges are on either side of the strain:
    - 2 gauges ↑ pressure
    - 2 ↓ gauges ↓pressure
  - this gives amplified potential change at the galvanometer

Flow

Ohm's law: $Q = \frac{\Delta P}{R}$

Flow (liquids or gases) can be: ***laminar*** , ***turbulent*** or *transitional*

Laminar Flow



- p = kv
- occurs in concentric cylinders of fluid/gas sliding over each other
- movement is steady, without eddies
- greatest velocity in centre (x2 mean flow) ⟹ falling to zero at walls

Hagen poiseulle equation:

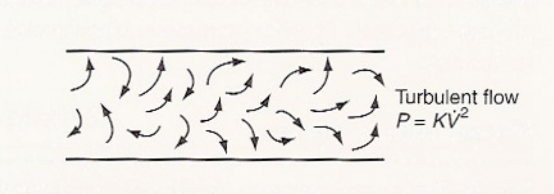
$$\boxed{Q = \frac{P \pi r^4}{8 \eta L}}$$

L = length of a smooth-walled tube
η = viscosity of fluid / gas (= shear stress/shear rate)
r = radius of tube

- equation can altered using Ohms law (Q=P/R) to express resistance to laminar flow:

$$R = \frac{8 \eta L}{\pi r^4}$$

Turbulent Flow



- p = kv^2
- in turbulent flow in a tube
    - with a rough surface: density is the important factor
    - with a smooth surface: density & viscosity is impt
- resistance defined by:

$$R = \frac{dl}{\pi r^5}$$

Reynolds number

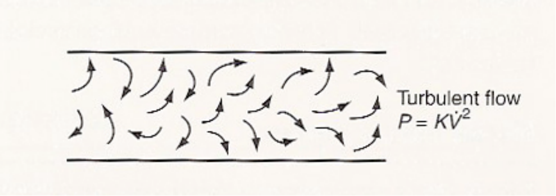
- =dimensionless number which predicts whether flow will be laminar or turbulent

$$\text{Reynold's no} = \frac{2rvD}{\eta}$$

Where r = radius, v = velocity, D = diameter, η = viscosity

- $\therefore$ if viscosity, density, diameter remain constant ⟹ velocity = determining factor
- Re number > 2000 ≈ turbulent
- critical flow
  - = flow at which transition takes place between laminar & turbulent
  - for typical anaesthetic gas value ~ same numerical value as internal diameter of airway concerned in mm
    - ↳ ie 9L/min for size 9 ETT
- critical velocity = velocity above which all flow = turbulent

Transitional Flow



- $p = kv + kv^2$
- combination of turbulent & laminar
- majority of flow in airway

Misc Flows

Venturi

- = where flow occurs in a tube with a contriction in which cross section ↓s and then ↑s

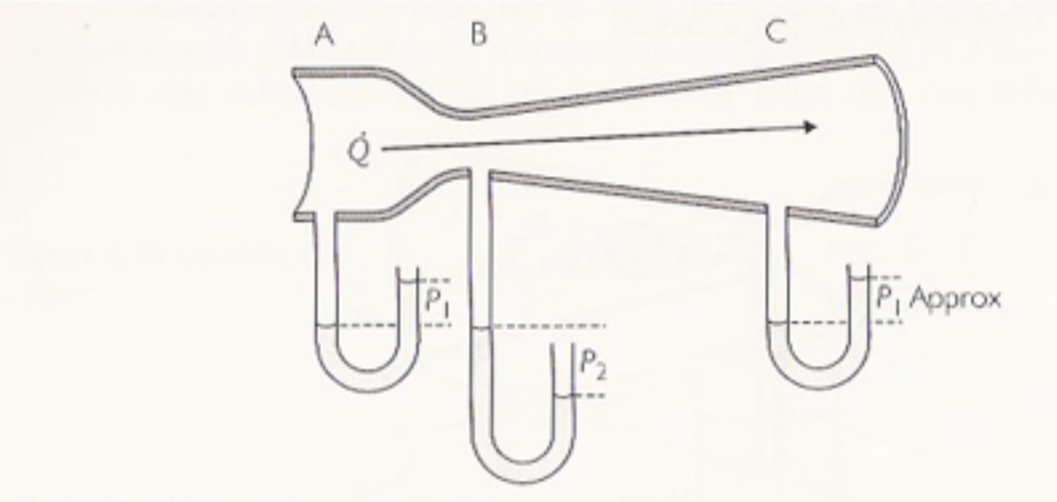


Figure 2.12 Principle of the Venturi

Bernoulli effect

- =fall in pressure during flow at a constriction in a tube
- caused by:
  - flowing fluid/gas contain energy in 2 forms:

    - kinetic = associated with flow
    - potential energy = assoc with pressure
  - at a narrowing see ↑velocity (ie ↑kinetic energy) but total energy remains constant ∴ must be a ↓potential energy (ie ↓pressure)

Entrainment

- air or fluid can get entrained through a side tube at a venturi because of this drop in pressure as described by Bernoulli
- this principle used in
  - nebulisers
  - venturi masks
  - injectors

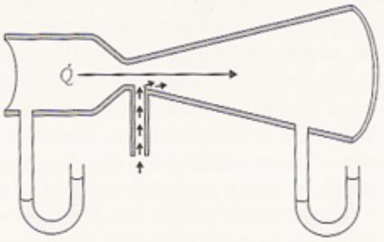


Figure 2.13 Fluid entrainment by a Venturi

Figure 2.14 Principle of a nebulizer

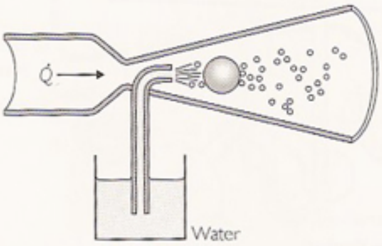
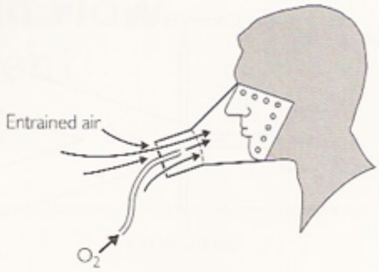


Figure 2.15 Venturi oxygen mask



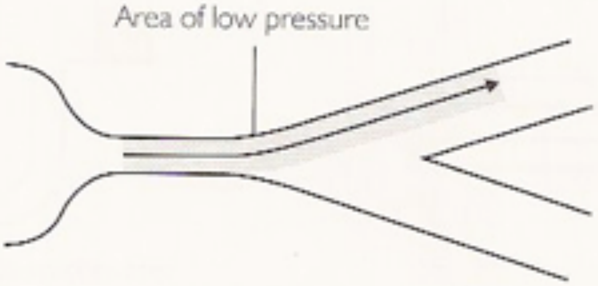
$$\text{Entrainment ratio} = \frac{\text{Entrained flow}}{\text{Driving flow}}$$

- jet entrainment = friction between gas at high speed ⟹ air pulls more air along with flow
- entrainment ratio = entrained flow / driving flow

Coanda Effect

- = behaviour of fluid/gas to follow only 1 limb of a Y junction after a narrowing in a tube
- due to development of lower pressure area between jet from a nozzle & an adjacent surface
- jet can be switched in direction by signal jets across nozzle
- this effect implicated in ineven ventilation of alveoli due to bronchi constriction

Figure 2.16 Coanda effect



Measurement of Gas Volumes & Flow

Volumes

- benedict spirometer
- vitalograph
- dry gas meter
- wright respirometer
- electronic volume monitor
- pneumotachograph

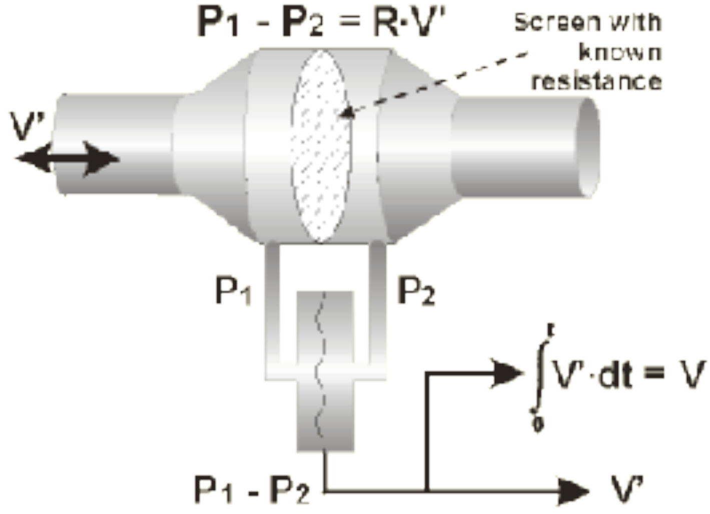
Gas Flow

- Variable orifice flow meters aka rotameters
- wright peak flow meter
- bubble flowmeter
- pneumtochograph

Variable Orifice Flow Meters

- consists of tapered glass tube with free floating bobbin inside
- bobbin has vanes so that it can rotate & not stick to glass due to static
- tapered tube ⟹
  - variable orifice around bobbin
  - depending on gas flow ⟹ constant pressure across bobbin
- ∴ pressure in equlibirum with gravity ∴ bobbin remains at constant level in tube for a given flow
- both laminar & turbulent flow are measured
  - ↳ ∴ viscocity & density of gas impt ⟹ need careful calibration of gauge to specific gas
- conductive strip or clear conductive coating is applied to tube to prevent electrostatic charge build up

Pneumatochograph



- principle: $Q = \frac{P1 - P2}{R}$ ie is Ohms law: F= P/R

- need measuring head with a gauze screen of
  - known resistance
  - large diameter ⟹ to ensure laminar flow
    - ↳ ↑diameter ⟹ ↓↓↓↓velocity ⟹ Reynolds defines ↑chance laminar flow
- adv:
  - continuous flow recorder
  - rapid changes can be measured
  - can also measure volum by integration of the flow through it electronically
  - very accurate
- disadv:
  - laminar flow dependant on viscocity; turbulent flow on density
    - ↳ ∴ diff gas used changes accuracy
  - temp changes effects viscocity & density ∴ calibration
    - ↳ to counter this usually contains a heating element to keep at constant temp
  - water condensation on the gauze screen can cause change in resistance
    - ↳ also prevented by heating

Temperature

see physiology section on thermoregulation

Gas Analysis

- O2
- CO2
- volatiles
- (pH electrode)

Oxygen Analysis

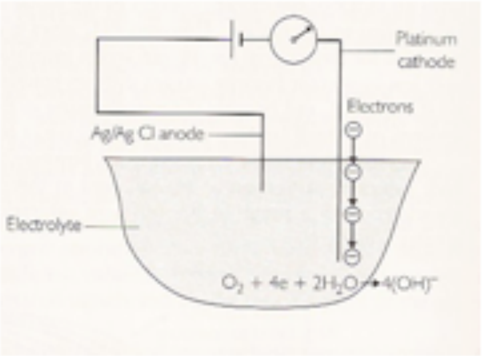
- variables to measure:
    - partial pressure (PO2)
    - O2 content (CaO2)
    - O2 saturation (SpO2)

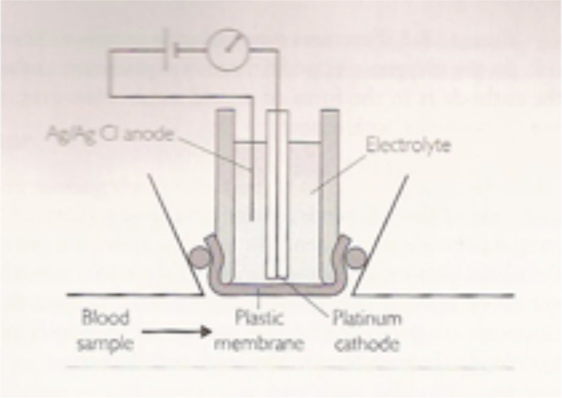
Partial Pressure Measurement

- diff methods:
    - polarographic method
    - fuel cell
    - paramagnetic method
    - mass spectometry
    - raman scattering
    - other:
        - US
        - UV
        - gas chromatography
        - magnetic acoutstic spectometry
        - fluorescence

Polarographic

- aka Clark electrode = can measure PO2 in gas mixtures as well as from blood samples:

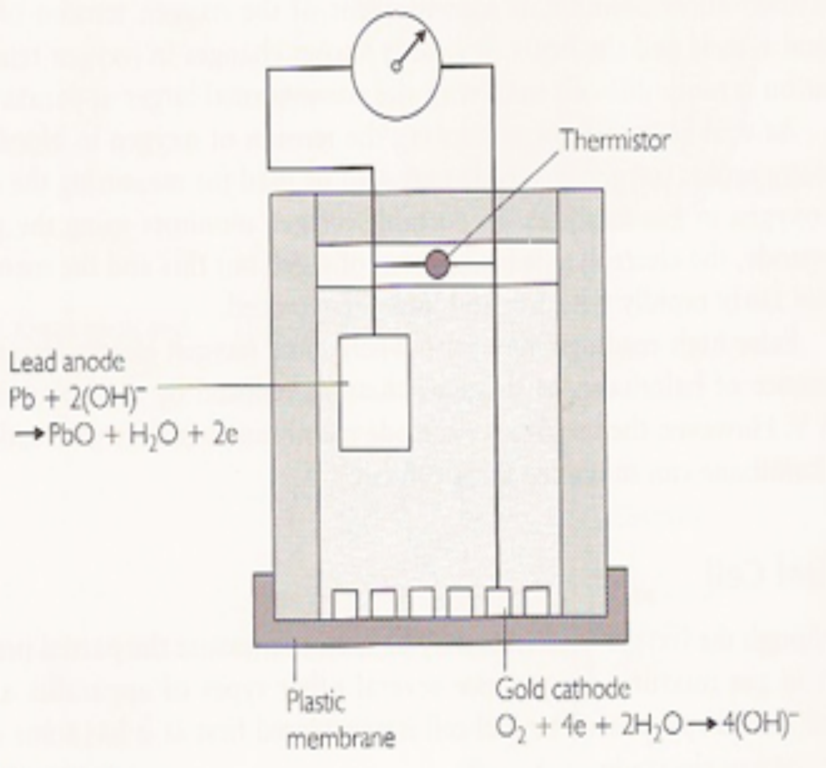




- O2 from either a gas or blood sample crosses a plastic membrane into a electrolyte solution (KCl)
  ↳ plastic membrane prevents elctrode direct contact with blood as would lead to protein deposits & error
- O2 then participates in an electro-reduction reaction at a platinum cathode
- electrons are available for this reaction at the cathode due to 0.6v battery at in circuit
- circuit completed by silver/silver-chloride anode (which also placed in electrolyte solution
- result:
    - more O2 available at platinum cathode ⟹ more electrons taken up at cathode ⟹ greater current flow
      ↳ current flow = linear & proportional to PO2

- reactions at electrodes:
  - cathode (reduction of O2): O_2 + 4 electrons + $2H_2O$ ⟹ $4(OH^-)$
  - anode (oxidation of Ag): Ag + Cl (from KCL) ⟹ AgCl + electron
  - ↳ for every molecule of O2 reduced ⟹ 4e- supplied to electrical circuit
- role of 0.6v battery:
  - ensures linear response for current vs O2
  - ↓s interference from reduction of other gases
- temp must also be controlled carefully at 37C

Fuel Cell



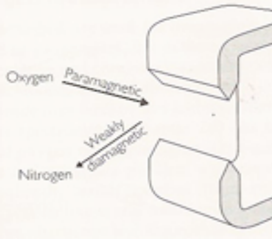
8 Fuel cell

- = very similar to Clark electrode but:
  - no battery needed ie no polarising current needed
  - cathode = gold mesh
  - anode = lead
  - electrolyte = KOH
  - reaction at cathode: O2 + 4 e^- + 2H2O ⟹ 4(OH-) ie same as Clark!
  - reaction at anode: Pb + 2(OH-) ⟹ PbO + H2O + 2 e^-
- current flow ~ PO2
- used in some modern anaesthetic machines eg some Draegars

Paramagnetic

- used in some modern anaesthetic machine eg Datex Ohmeda
- principle: O2 is paramagnetic ie can be drawn into a magnetic field

Figure 18.9 Paramagnetic property of oxygen



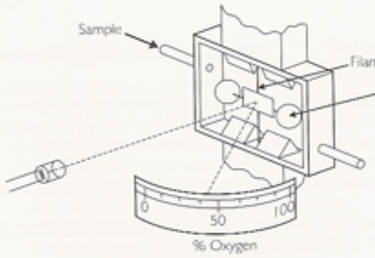
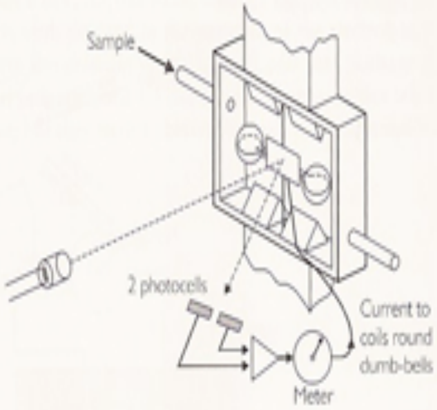


Figure 18.10 Simple paramagnetic oxygen analyser

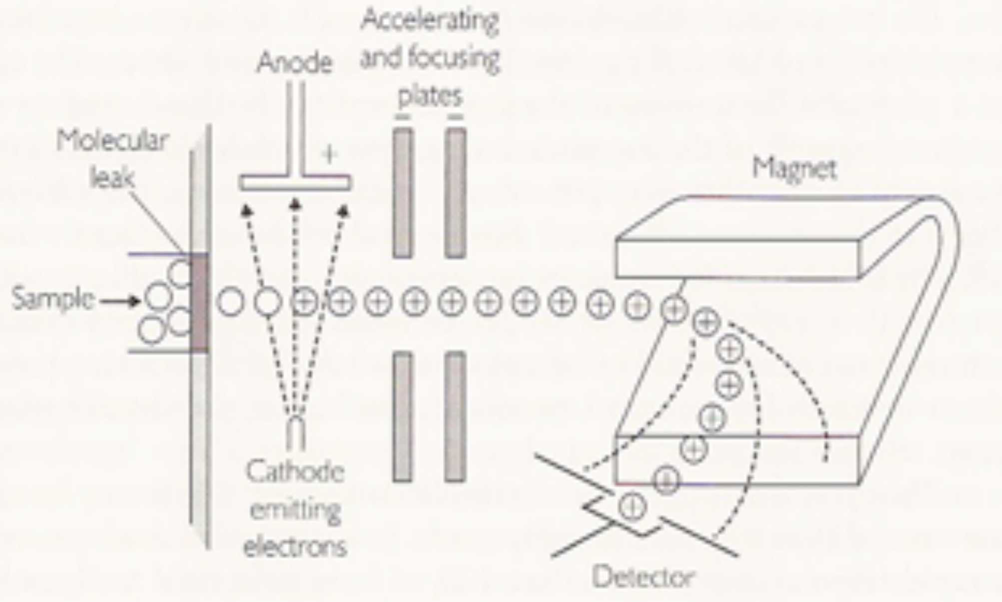
Figure 18.11 Null-deflection type of paramagnetic oxygen analyser



- in most simple form:
  - O2 drawn into magnetic field ⟹ displacement of nitrogen (which is contained in glass spheres at ends of rod - looks like dumbells)
  - N2 is weakly diamagnetic (tend to move out of magnetic field)
  - deflection of dumbells is registered by reflected light from a LED source & displayed
- adv:
  - can be set as a null-deflection system ie ↑↑sensitivity + gain
  - fast
- disadv:
  - must be calibrated with 100% O2 & 100% nitrogen
  - affected by water vapour ∴ gases must be dried over eg silica gel before entering
- more modern devices have ↑ed sophistication

Mass Spectrometry

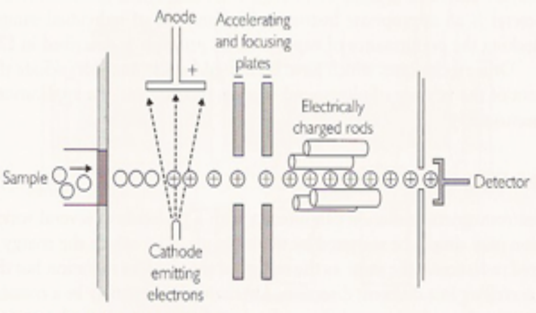
- many gases, incl anaesthetic gases measured this way



20.6 Principle of the mass spectrometer

- sample is drawn through a tube into a the sample chamber by a pump
- molecular leak permits a few molecules of sample substance to diffuse into an ionisation chamber
- in chamber they are bombarded by beam of electrodes passing from a hot cathode to anode

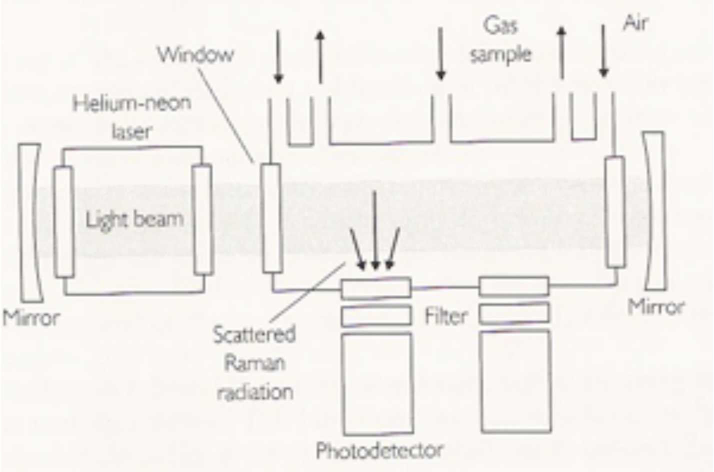
- when electrons collides with gas molecules ⟹ some become charged ions ⟹ then accelerated out of chamber in narrow beam by accelerating & focusing plates
- stream of ions then pass through strong magnetic field ⟹ deflects them in an arc
- the deflection is picked up by a detector
- deflection:
    - = proportional to the amount of O2 = as identified by its mass
    - lighter ions ⟹ deflected most
    - ∴ different gases form different streams
- ∴ mass spectrometers identify compounds by their mass numbers
- different streams can be identified & isolated by single mass spectrometer eg quadrupole mass spectrometer



0.7 Quadrupole mass spectrometer

- disadv of mass spectrometer:
    - problems with some gases eg CO2 - breaks up into CO & O ⟹ both detected
    - CO2 & N2O both have same mw (44)
        ↳ solution is to measure NO (breakdown product from N2O) & use it as an index for N2O
    - large machine
    - expensive
    - sampling delay

Raman Scattering



Gas analyser based on the Raman effect

- raman effect:
    - light interacts with a gas molecule & changes the rotational or vibrational energy of the molecule
    - resulting transfer of energy from or to the light, changes its wavelength by amounts that are specific to molecule concerned
    - ∴ monochromatic (1 wavelength) radiation is changed, when passing through gas, into a spectrum of different wavelengths (= scattering)
        ↳ this depends on the structure of individual molecules
- the type & concentration of molecules in a gas mixture can be determined by this principle
- advs:
    - accuracy - similar to mass spectrometer
    - breath by breath analysis
    - identify different types of gases

Ultrasound

- velocity of sound varies with the concentration of the gas it travels through
- US transducer emits a signal that is reflected & picked up
- delay in pick up varies with O2 concentration

Fluorescence

- fluorescent light from certain dyes can be quenced by O2
- this dye is incorporated in fibreoptic catheters
- dye is excited by light at 385nm ⟹ producing emitted light at 515nm
- the ↓in light emitted is directly proportional to O2 tension

Oxygen Content Measurement

Direct Measurement

- Van Slyke apparatus:
  - = gold standard
  - blood is haemolised (by lactate)
  - Hb converted to MetHb (by adding saponin & potassium ferricyanide)
  - ∴ O2 is released ⟹ collected in closed apparatus
  - amount of O2 is measured via manometric method:
    - measure pressure changes in constant gas volume (PV = nRT)
  - disadv:
    - needs large sample + slow process
    - doesnt measure dissolved amount of O2
    - high degree of operator skill required
- Lex-O2-Con:
  - blood haemolised (by distilled water)
  - O2 enters carried gas bubbles ⟹ transported to a fuel cell
  - in fuel cell:
    - reaction $O_2 + 4e^- + H_20 \Rightarrow 4(OH^-)$ at cathode
    - current produced by electrons = proportional to total number of O2 molecules

Calculated

- ie from PO2, Hb, SaO2

$$CaO_2 = [\,Hb \times SaO_2 \times 1{,}39\,] + (\,PaO_2 \times 0.003) = \text{ml } O_2 / 100 \text{ ml blood}$$

- errors via this method:
  - SaO2 - oximetry sources of error
  - Huffners number -
    - predicted number is 1.39
    - actual number is 1.3 - 1.36
    - due to non-functional Hb eg COHb, or metHb
  - foetal HbF

Oxygen Saturation measurement

- spectrophotometry:
  - oximeter (SaO2)
  - pulse oximeter (SpO2)

↳ see monitoring

Carbon Dioxide Measurement

- from gas sample:
    - infrared absorption
    - mass spectrometry
    - raman scattering
    - chemical colorimetric
    - gas chromatography
- from blood sample:
    - Severinghaus CO2 - electrode

Infrared Absorption

- principle method = absorption of infrared radiation
    - IR radiation shines through sampling & reference chambers
    - detector measures the difference in absorption between the two
- this technique used for CO2 detection & volatile sampling
- NB only gases with 2 or more different atoms in the molecule can be measured this way

  ↳ ie O2 cannot be
- to differentiate between CO2 & eg volatile agent: analyser must look at different wavelengths:
    - volatiles = 3.3 um
    - CO2 = 4.3um
    - N2O = 3.9

  ↳ wavelength correlates to where gas has strong absorption
- monochromatic analyser = unable to differentiate between diff volatiles
- polychromatic analyser = adds additional wavelengths to determine which agent responsible for 3.3um absorption

  ↳ ∴ can differentiate diff volatiles

Gas Chromatography

- used for:
    - a mixture of gases
    - blood samples - it vaporises the sample at the injection port with heat
- components:
    - stationary phase = silica alumina & silicon oil coating
    - mobile phase = carrier gas (eg N2) + sample gas
    - detectors:
        - flame ionisation - for detecting organics
        - thermal conductivity - for inorganics
        - electron capture detector - for halogenated substances

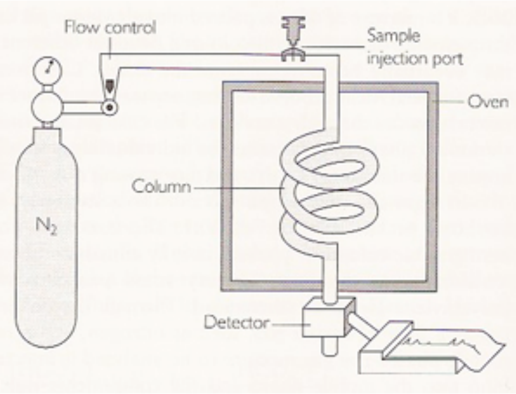
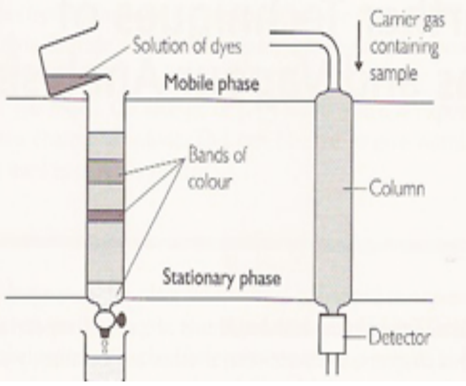


Figure 20.1 Principle of liquid chromatography (left) and gas chromatography (right)



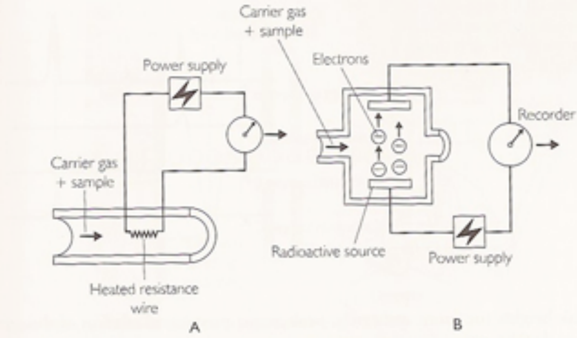
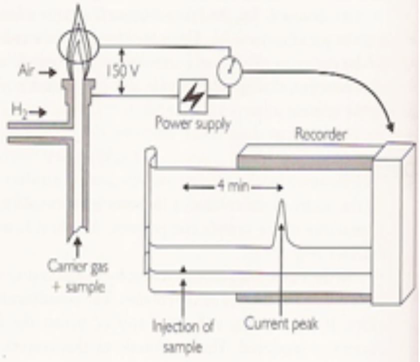


Figure 20.4 (A) Thermal conductivity detector, (B) electron capture detector

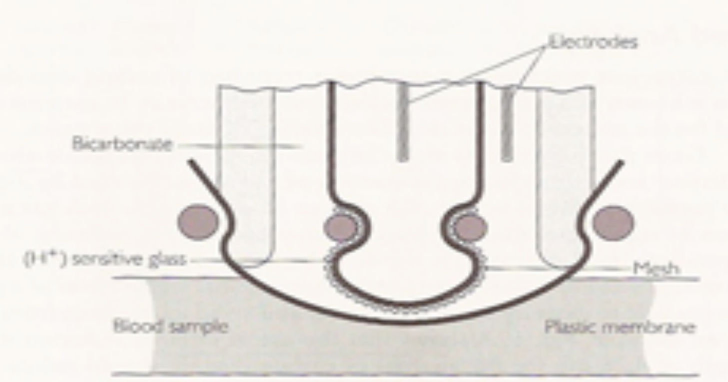
Figure 20.3 Flame ionization detector



- principle of chromatography:
  - components of sample gas pass through column (stationary phase)
  - speed through this phase dependant on their differential solubility between 2 phases
  - appearance of components detected at outlet then detected by diff detectors as outlined above
- ∴ each substances progress has its own characteristic rate
  - time between injection & appearance at detector used to identify it
    ↳ = retention time

Severinghaus CO2 Electrode

- used to measure CO2 directly from blood sample
- principle:
  - to measure CO2 from liquids eg blood sample
  - methods based on H+ measurement:
    - $CO_2 + H_2O \Rightarrow H_2CO_3 \Rightarrow H^+ + HCO3^-$
    ↳ CO2 tension ∴ directly proportional to H+ concentration
- electrode equiipment:
  - apparatus incorporates hydrogen ion sensitive glass with electrodes either side of it
  - H sensitive glass in contact with a thin film of NaHCO3 solution (acts as a buffer) in a nylon mesh
  - mesh is fixed over the glass tip with an o-ring
  - liquid to be tested is separated from the nylon mesh & bicarb by a plastic membrane
  - plastic membrane is permeable to CO2 and is also attached by o-ring
  - at tip of electrode:
    - CO2 diffuses thru plastic into the mesh impregnated with NaHCo3 solution ⟹
    - CO2 combines with water present $\Rightarrow H_2CO_3 \Rightarrow H^+ + HCO3^-$
    - electrode potential depends on the conc of H ions
      ↳ ∴ proportional to voltage measured in circuit
- must be kept at 37deg
- must be calibrated with known mixtures of Co2/O2 before use



.3 Severinghaus CO_2 electrode

Volatile Agent Measurement

- infrared absorption - monochromatic or polychromatic analysers (Datex AS/3)
- piezo-electric crystal resonance technique (Siemens, Engstrom)
- photo-acoustic analysers (hewlit Packard)
- Raman scattering (Ohmeda Rasca)
- mass spectometry
- refractrometry
- gas-liquid chromatography
- other: laser analysers, UV, solubility, density

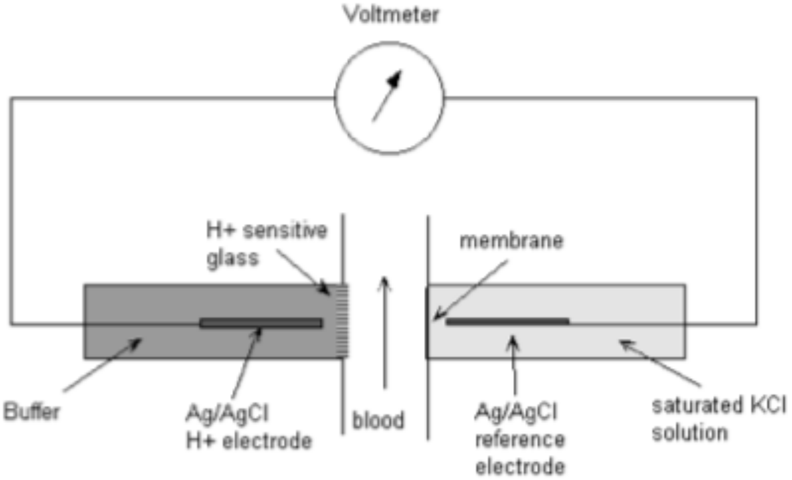
Piezo-electric crystal resonance

- when electrical potential applied across a quartz crystal ⟹ contracts
- if specific AC current applies ⟹ crystal oscillate at resonant frequency
- crystal coated with silicon oil:
  - volatile will dissolve in according to specific oil:gas partition coefficient
  - ⟹ change in resonant frequency ⟹ detected
- an uncoated crystal is incorporated as a reference
- problems:
  - does not distinguish which volatile
  - interference from water vapour (remove by heating)
  - CO2, O2, N2O are not measured

Raman Scattering

- as per previously
- monochromatic laser light absorbed by substance in question
- light emitted at different wavelengths + frequencies
- adv:
  - can measure O2, CO2, N2O, N2 & volatiles
  - breath by breath analysis
  - accuracy ~ mass spectrometer
  - can identify diff volatiles

pH Electrode



(similar to Severinghaus electrode in CO2 measurement)

- H+ electrode = ion selective elctrode dependant on H ion sensitive glass at it’s tip
- potential develops across glass that is dependant on difference of H+ across it
- H+ within H+ electrode kept constant by buffer solution ∴ potential across glass is dependant on H+ in blood sample
- reference electrode used to complete circuit which has a membrane at tip to avoid contamination
- both electrodes are silver in contact with its chloride which is in turn in contact with a solution of chloride ions
  - H+ electrode - surrounded by buffer
  - reference electrode - surrounded by KCl
- potential difference between the electrodes is measured & converted into a direct reading of H+ or pH
- only variable in circuit is difference in pH between the inner buffer of the H+ electrode & that of sample
  - ↳ this difference creates the potential difference which measured on volt meter
- temp control in imp - 37deg

Misc Laws, Definitions, Terminologies

Ficks Law of Diffusion

- not to be confused with Fick's principle!!
- The rate of diffusion of a substance across a unit area is proportional to its concentration gradient.
  ↳ (This applies to a homogenous phase)

$Js = D.A.\ \Delta c/\Delta x$

Js = rate of diffusion,
A = surface area,
Δc = concentration gradient,
Δx = thickness of membrane
D = a constant = ~ solubility / $\sqrt{mw}$

Grahams Law

- The rate of diffusion of a gas is inversely proportional to the square root of its molecular weight (mw).
  ↳ this law only applies in certain cases when dealing with membranes and can also be applied to liquids

Osmosis

Osmosis:

Movement of *solvent* molecules across a semipermeable membrane into a region with higher conc of solute, so to equalise conc on both sides

Osmotic pressure:

The hydrostatic pressure required to ***prevent*** movement of *solvent* molecules by osmosis across a *semipermeable* membrane.

predicted with $P = \frac{nRT}{V}$

Molality:

Is the number of moles of solute per **kg** solvent. Molality represents the **number** of particles of the particular substance present.

Osmolality:

- Is the no of osmoles of solute per **kg** solvent. One osmole = 6×10^{23} particles
- NB **no** distinction is made about the type of particle present

↳ many different particles may be present.
- NB: it is *independent of temperature* or volume of solvent
- Units = mosmoles / kg

Osmolarity:

- Is the no of osmoles of solute per liter of solvent.
- altered by:
    - changes in temperature
    - volume of the solvents.
- Units = mosmoles / l

Tonicity:

- Is the *effective* osmolality of a solution (c/f to eg plasma, ECF, ICF etc).
- ∴ a measure of *only those particles effective at exerting an osmotic force across a membrane*.
- ∴ tonicity = Total osmolality minus ineffective osmolality.

"Effective" osmoles: = most solutes = those that does not cross membranes easily and are thus effective at exerting an osmotic force across the membrane in question.

"Ineffective osmoles": Some solutes cross cell membranes, eg urea + glucose*. Thus, they are not effective at exerting an osmotic force across the membrane, but they do contribute to the *total* osmolality.

*Note: - **glucose** moves via facilitated diffusion across fat + muscle cells via action of Insulin. Thus, in diabetes, it becomes an effective osmole as fat + muscle cells form ~ 80% of cells in the body.
- **urea** is an effective osmole at the BBB, which it crosses very slowly compared to H2O. Thus "hypertonic" urea (and also manitol) is hypertonic in relation to the BBB, and therefore effective in the Rx of cerebral oedema.

Colligative Properties

= those properties of a solution that depend only on the particle concentration, ie the number of particles per volume.

- They are:
    - *SVP depression,*
    - *boiling point elevation,*
    - *freezing point depression*
    - *osmotic P.*

- An example of where this is NB is glucose which is stored as glycogen.
    - Many glucose molecules combine to form one glycogen molecule.
    - One glucose molecule exert exactly the same osmotic pressure over a semipermeable membrane than does one glycogen molecule.
    - Put another way, all the glucose molecules which make up a glycogen molecule would have exerted an immense osmotic pressure if they were individual (non-combined) molecules.