





Physiological Signals in Respiratory System

呼吸系統的生理訊號

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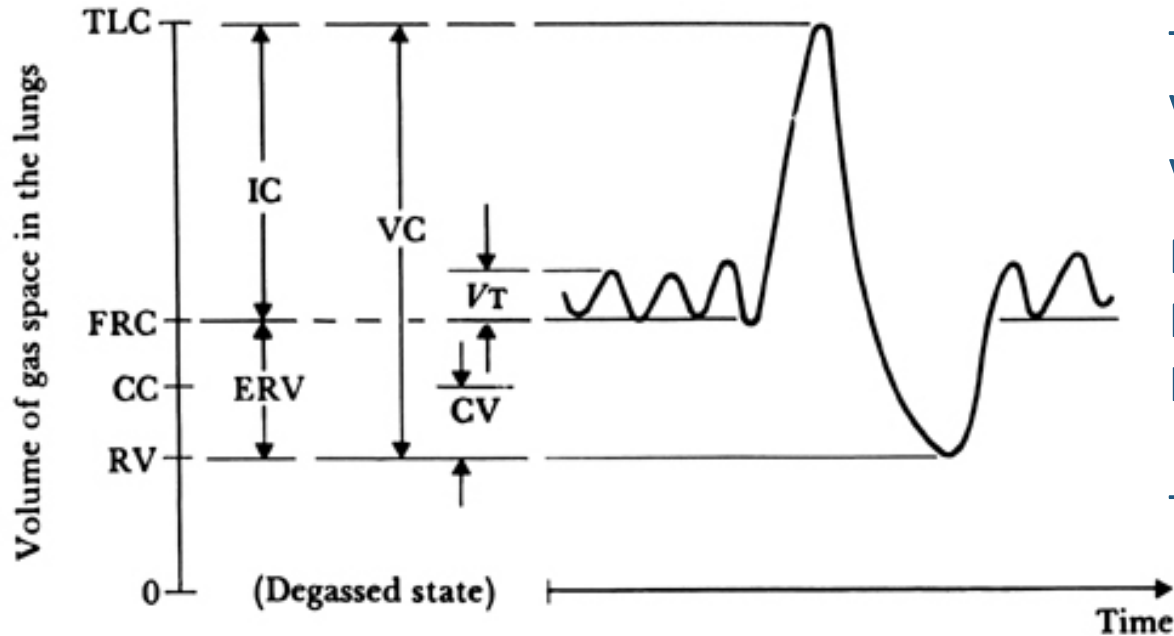




Respiratory system

- A system used for gas exchange
 - Trachea, bronchus, lung
- Evaluation of its function
 - **Ventilation**: the movement of air into the lungs
 - **Distribution**: the distribution of inhaled gas in lungs
 - **Diffusion**: the exchange of O₂ and CO₂ at cellular levels

Volumes related to ventilation



TLC: total lung capacity

V_T : tidal volume

VC: Vital capacity

RV: residual volume

FRC: function residual capacity

IC: inspiratory capacity

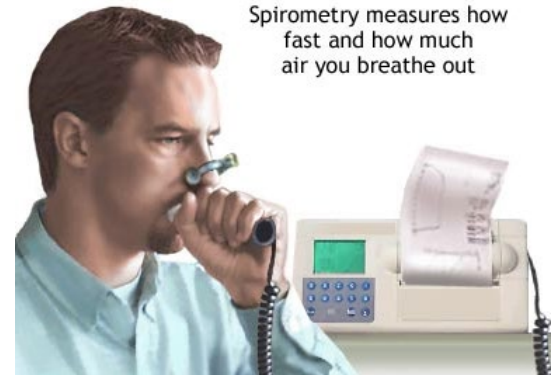
$$TLC = VC + RV = IC + FRC$$

Volumes related to ventilation

- Tidal volume
 - the volume of air moved in and out of the lung under normal respiration (~ 500 ml)
- Respiratory rate
 - number of breaths per minute
- Minute volume (minute ventilation)
 - the total amount of air exchanged per minute
 - Minute volume = V_T x respiratory rate

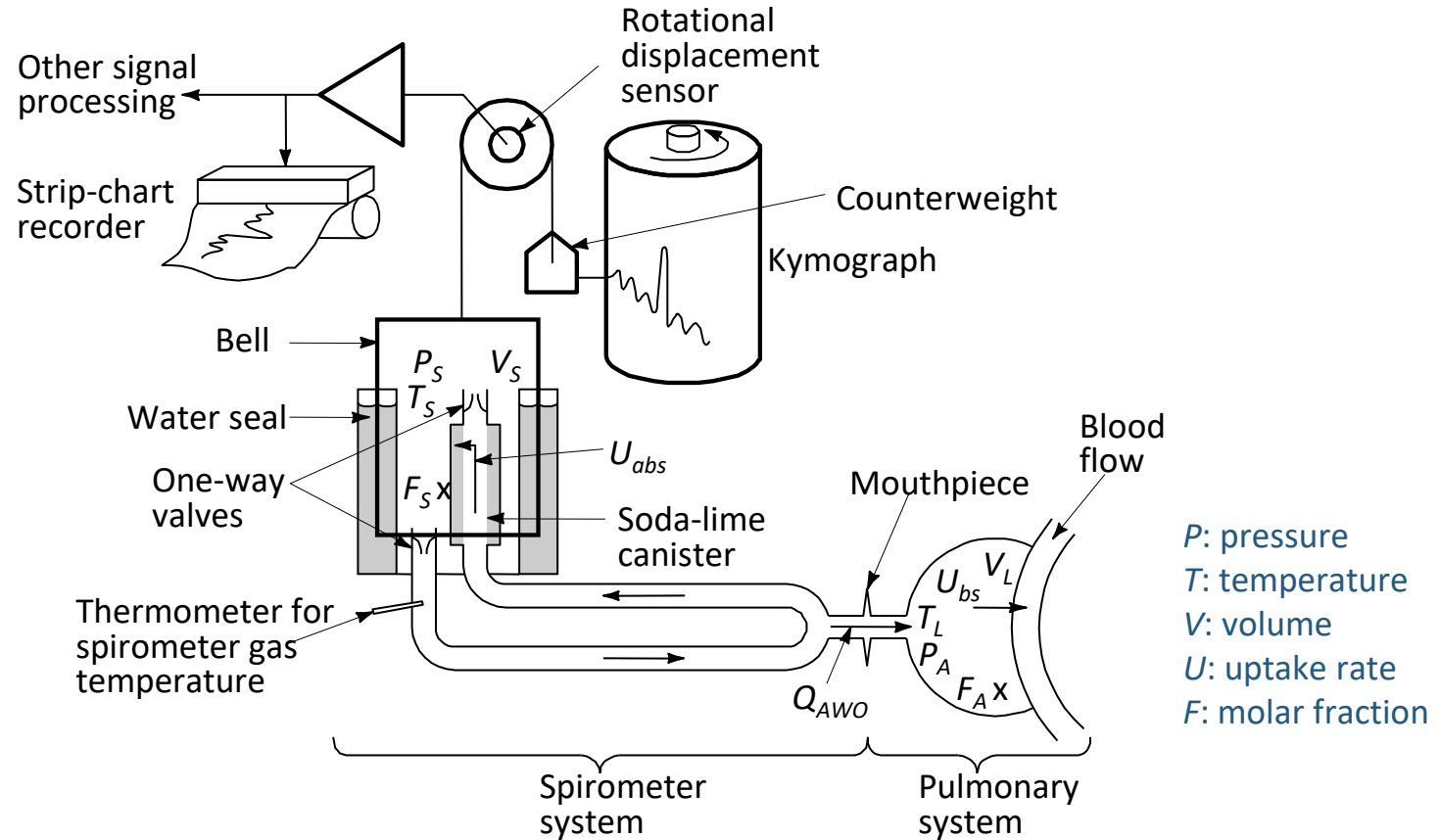
Measurement of respiratory volumes

- Spirometer
 - Measure the volume of air inhaled and exhaled through mouthpiece (with the airflow of noise being blocked)
 - Incapable of measuring residual volumes
- Pulmonary function test



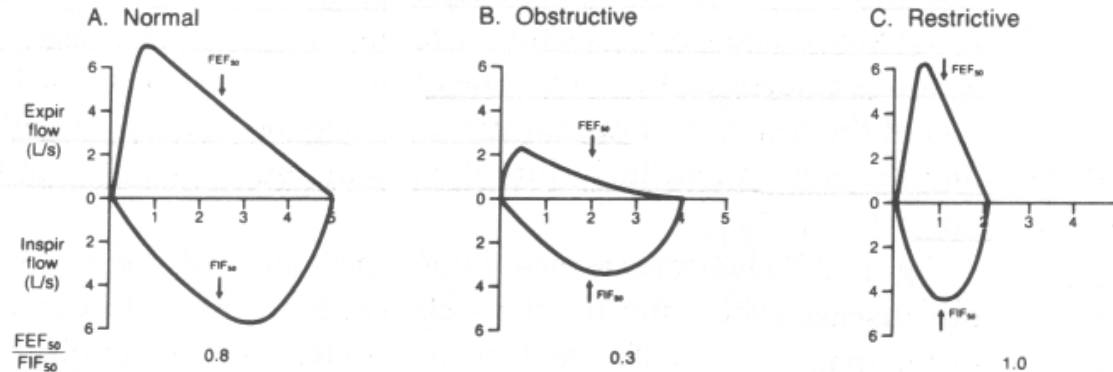
Spirometry measures how fast and how much air you breathe out

Water-sealed spirometer



Flow-volume curve by spirometry

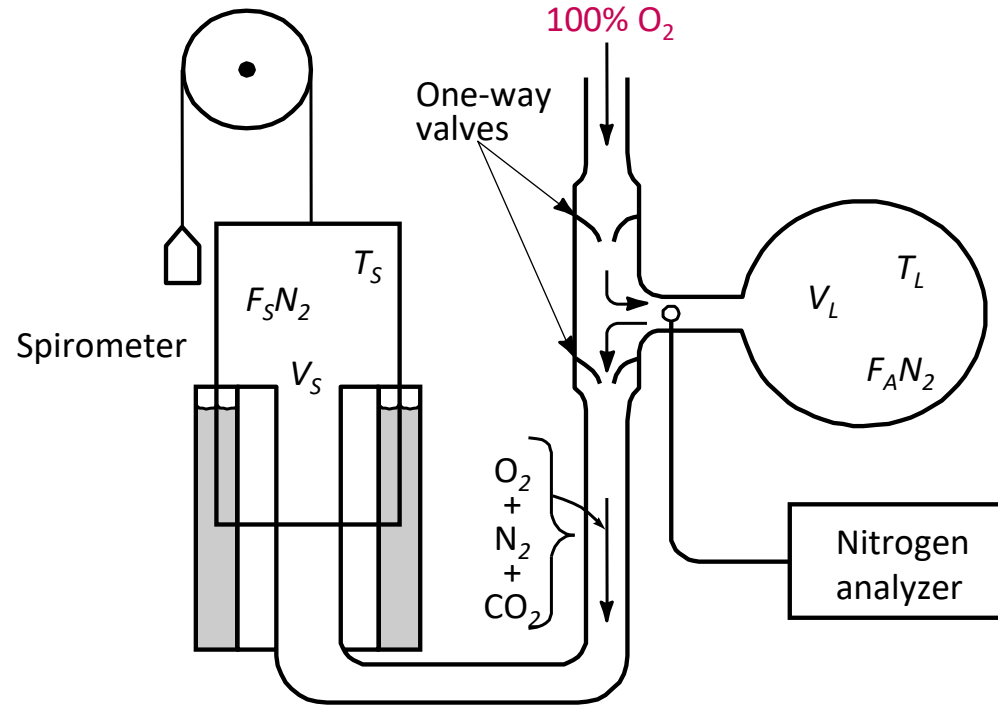
- Ask the patient to take an abrupt maximum effort inhale, followed by a maximum effort exhale



Nitrogen washout procedure

- Measure the absolute volume of lungs, such as TLC or FRC
- Ask the patient to breathe pure O_2
- Measure the expired volume and the N_2 concentration to estimate the lung volume
 - FRC and TLC

Nitrogen washout procedure



Whole-body plethysmography

- **Body box** for plethysmograph
- Measure FRC or TLC by using Boyle's law

- $$P \cdot V = (P - \Delta P)(V + \Delta V)$$

- $$FRC = V_{box} \cdot \left| \frac{\Delta P_{box}}{\Delta P_{mouth}} \right|$$

P_{mouth} : mouth pressure

P_{box} : box pressure

V_{box} : the free box volume outside the body



Photo credit: Wikipedia (Plethysmograph)

Plethysmography

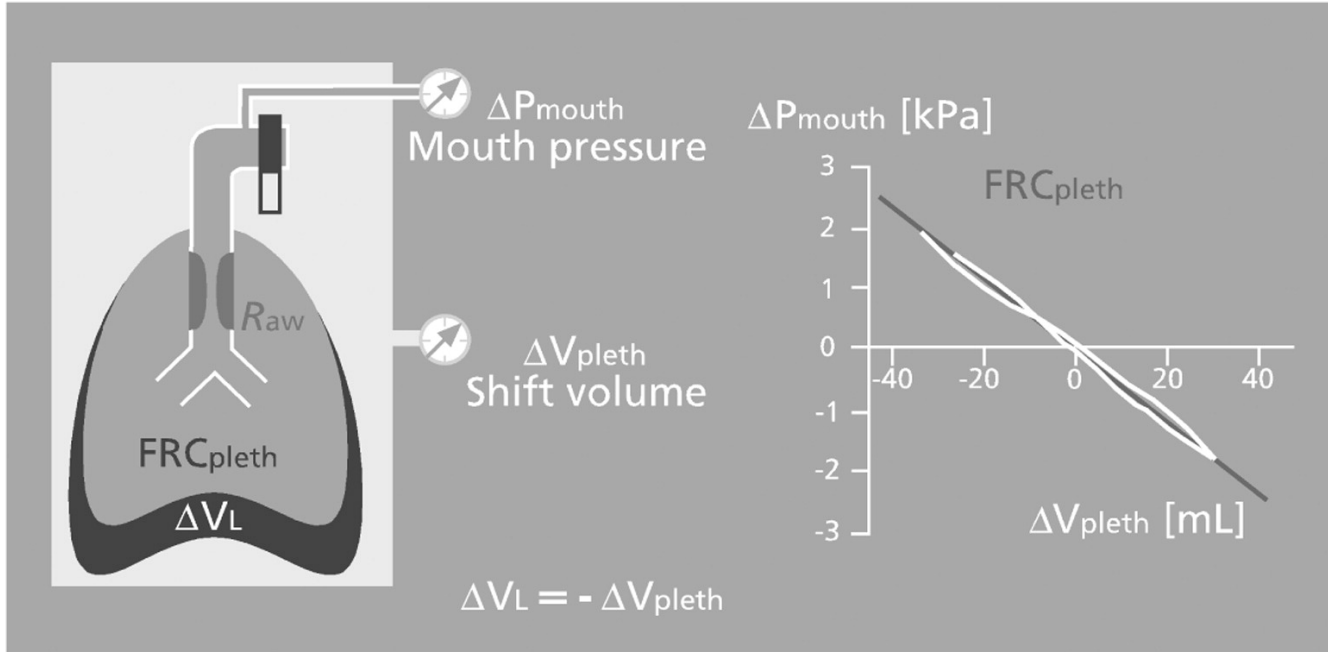


Photo credit: Wikipedia (Plethysmograph)



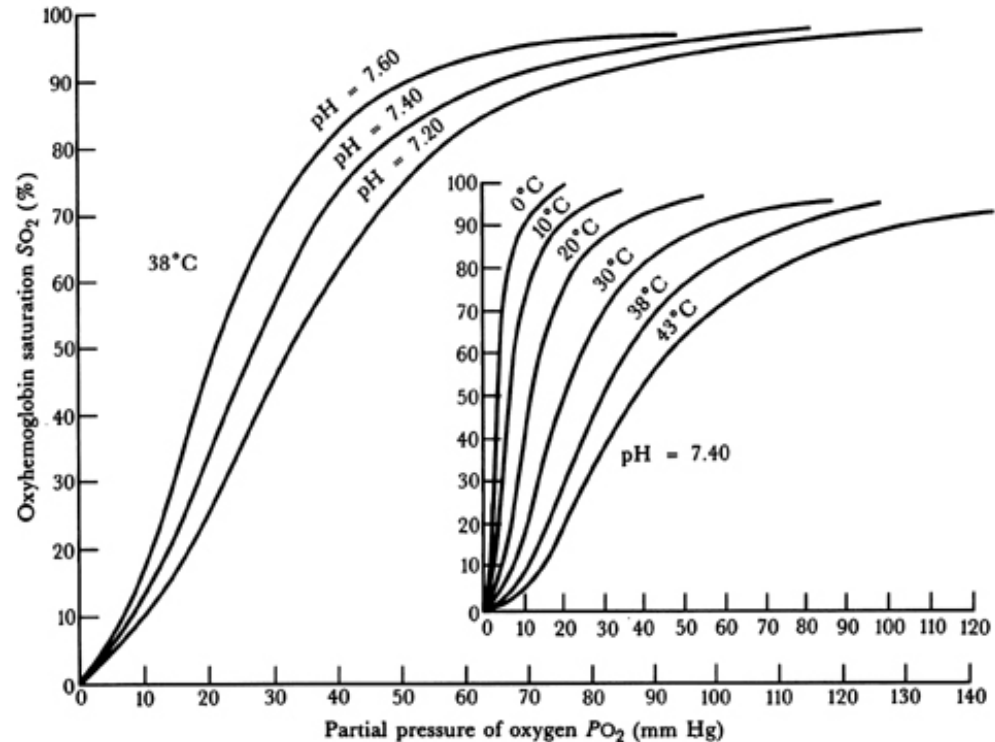
Distribution of blood gas

- Related to the function of respiratory and circulatory system
- Normal range in blood
 - Arterial pO_2 : 80-104 mmHg
 - Arterial oxygen saturation (SaO_2): 95-100 %
 - Venous pCO_2 : 33-48 mmHg
 - pH: 7.31~7.45

Oxygen in blood

- Oxygen is picked up into capillaries at alveoli.
 - 98% combined with hemoglobin (as HbO_2)
 - SO_2 : the fraction of oxygenated hemoglobin (HbO_2) to total hemoglobin
- pO_2 is generally proportional to SO_2
 - Also effected by **pH value** and **temperature**

HbO₂ dissociation curve



CO₂ in blood

- CO₂ is released from the pulmonary capillaries
- CO₂ is >20 times soluble than O₂ in blood
 - $\text{CO}_2 + \text{H}_2\text{O} \leftrightarrow \text{H}_2\text{CO}_3 \leftrightarrow \text{H}^+ + \text{HCO}_3^-$
 - pCO₂ can be estimated by pH value
- Hypercapnia: abnormally elevated CO₂ level in blood

Measurement of arterial blood gas

- The conventional method requires arterial blood samples
 - Highly invasive
 - Not available for real-time applications
 - Accurate
 - Measuring all parameters of interest, such as pO_2 , pCO_2 , pH, and concentration of electrolytes



Clark-type pO_2 sensor

- Reduction-oxidation reaction

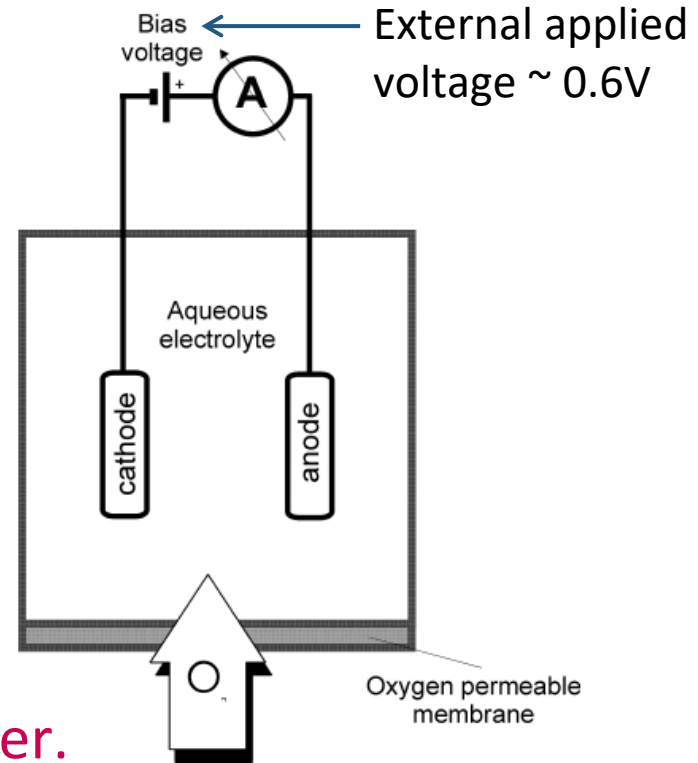
- Cathode: reduction



- Anode: oxidation

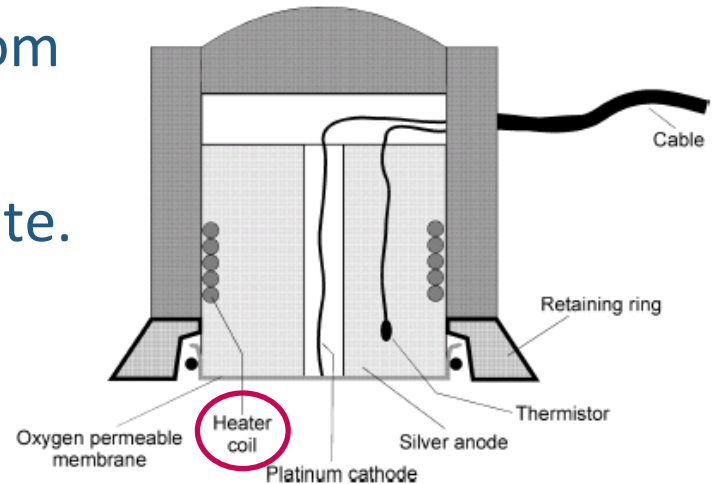


The current increases as pO_2 goes higher.



Transcutaneous pO₂ sensor

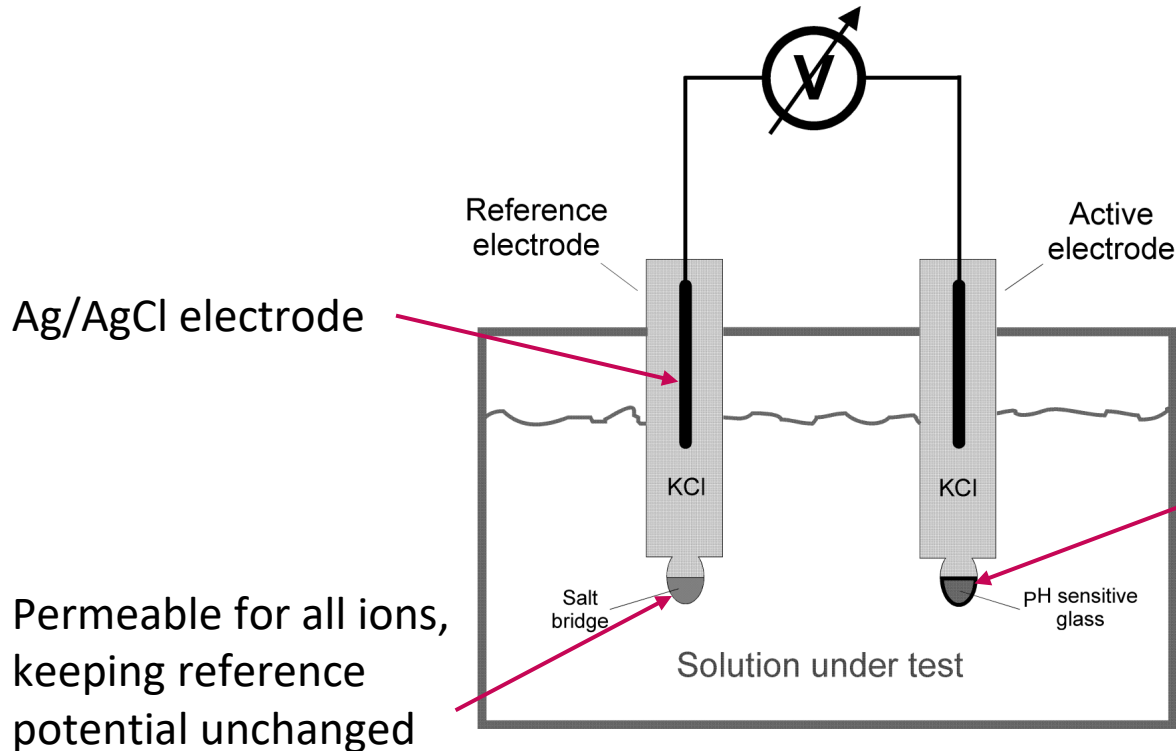
- Attached on the skin, instead of being immersed in blood or tissue fluid.
 - Measure oxygen diffusing from blood through the skin.
 - Non-invasive, but less accurate.



pCO₂ and pH value

- pCO₂ (in the range of 10-90 mmHg) is linearly related to pH value
 - Normal range of pCO₂: 33-48 mmHg
 - $\text{CO}_2 + \text{H}_2\text{O} \leftrightarrow \text{H}_2\text{CO}_3 \leftrightarrow \text{H}^+ + \text{HCO}_3^-$
 - $\text{pH} = -\log_{10}[\text{H}^+]$
 - Calibration according to temperature

pH electrode



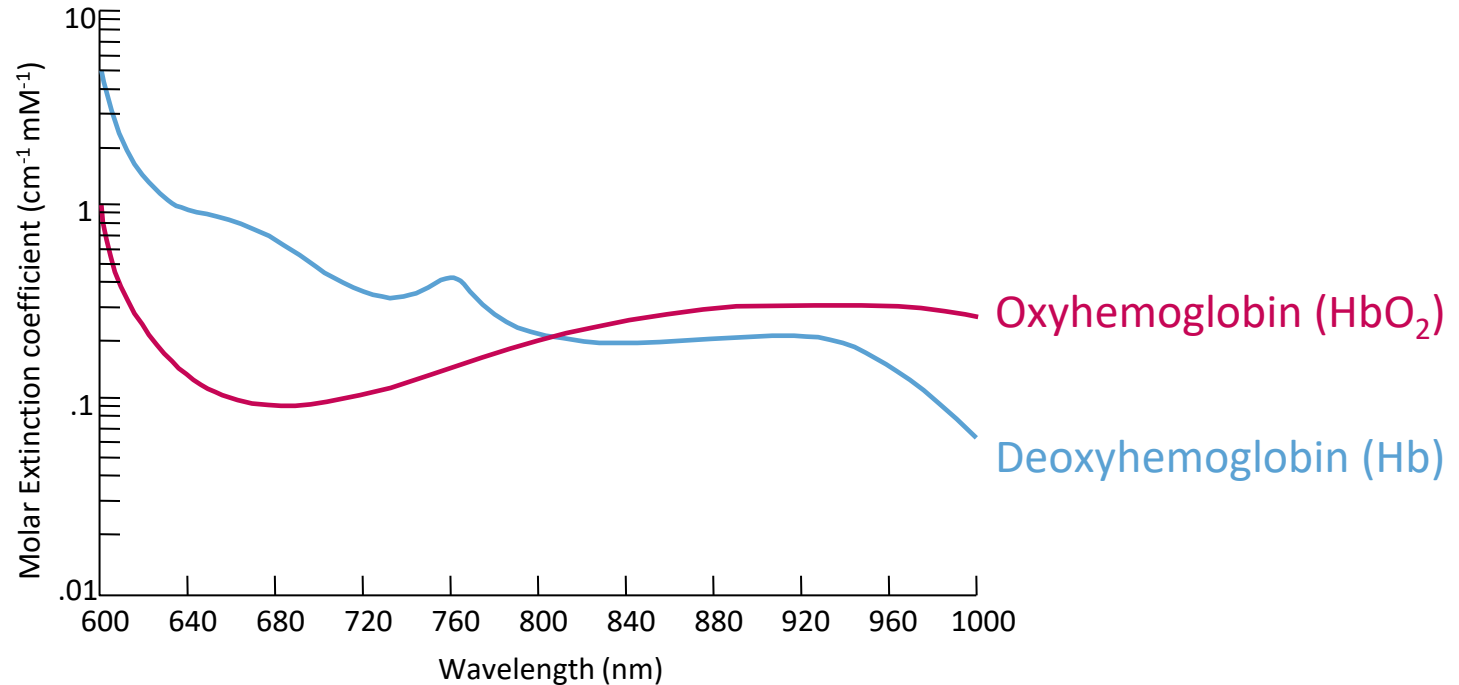
A lithium-doped glass electrode, of which only H^+ ions can bind on the surface to develop an electric potential

Permeable for all ions, keeping reference potential unchanged

Optic-based methods for blood test

- EM waves attenuate quickly in human tissues.
 - The **near infrared** (λ : 650-1350 nm) shows maximum penetration depth
 - Scattering and absorption
- The attenuation of HbO_2 and Hb are functions of wavelength, respectively.

Attenuation of HbO₂ and Hb



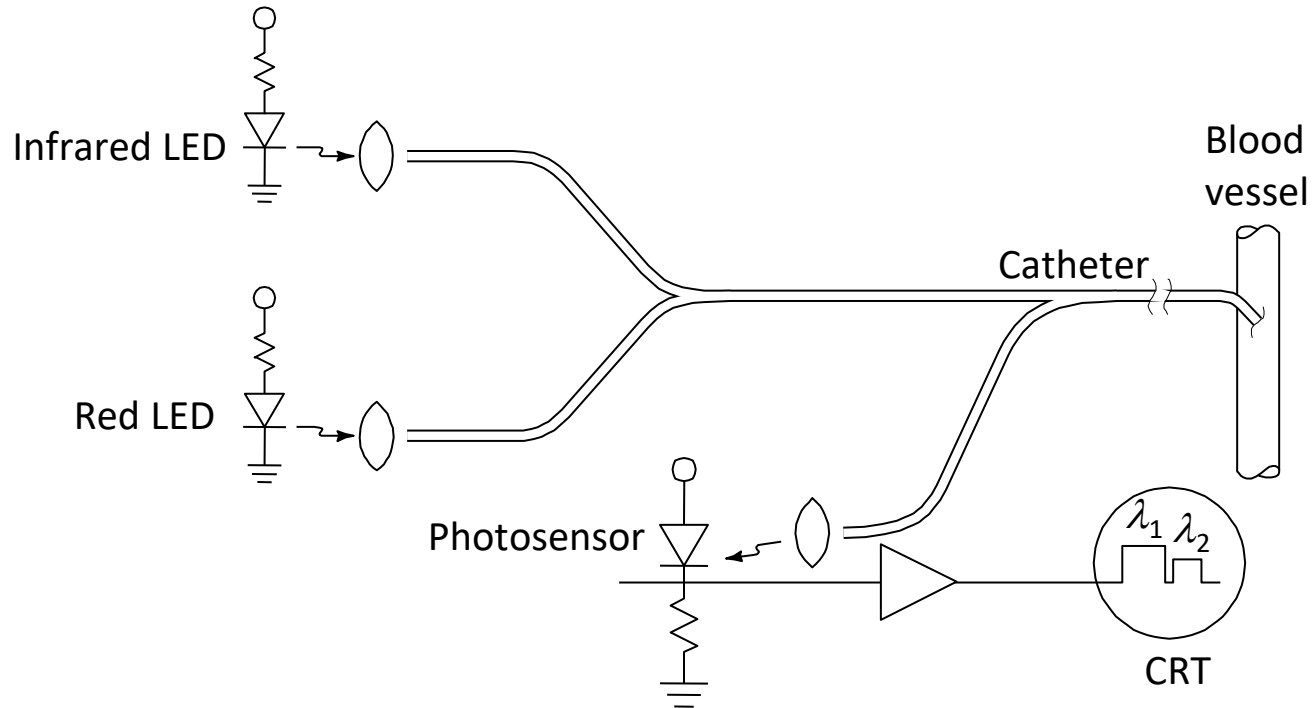
Extinction coefficient: the attenuation coefficient due to absorption and scattering



Oxygen saturation

- The fraction of HbO₂ can be calculated with at least two different wavelengths.
 - Oxygen saturation (SO₂)
 - Ex: **red light** (660 nm) and **infrared** (805 nm)
- Invasive and real-time

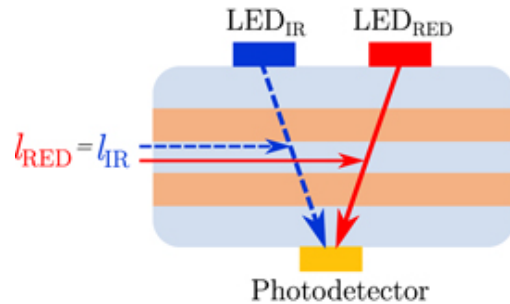
Intravascular fiber-optic catheter



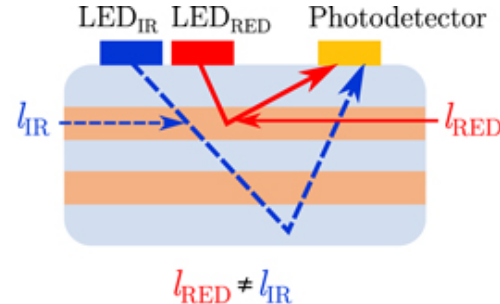
The oximeter catheter system

Pulse oximetry

- **Non-invasive** measurement of SO_2
 - Measure on the surface of skin
 - SpO_2 : peripheral oxygen saturation
- Transmissive and reflective pulse oximeters



(a) Transmissive PPG sensor (tPPG)

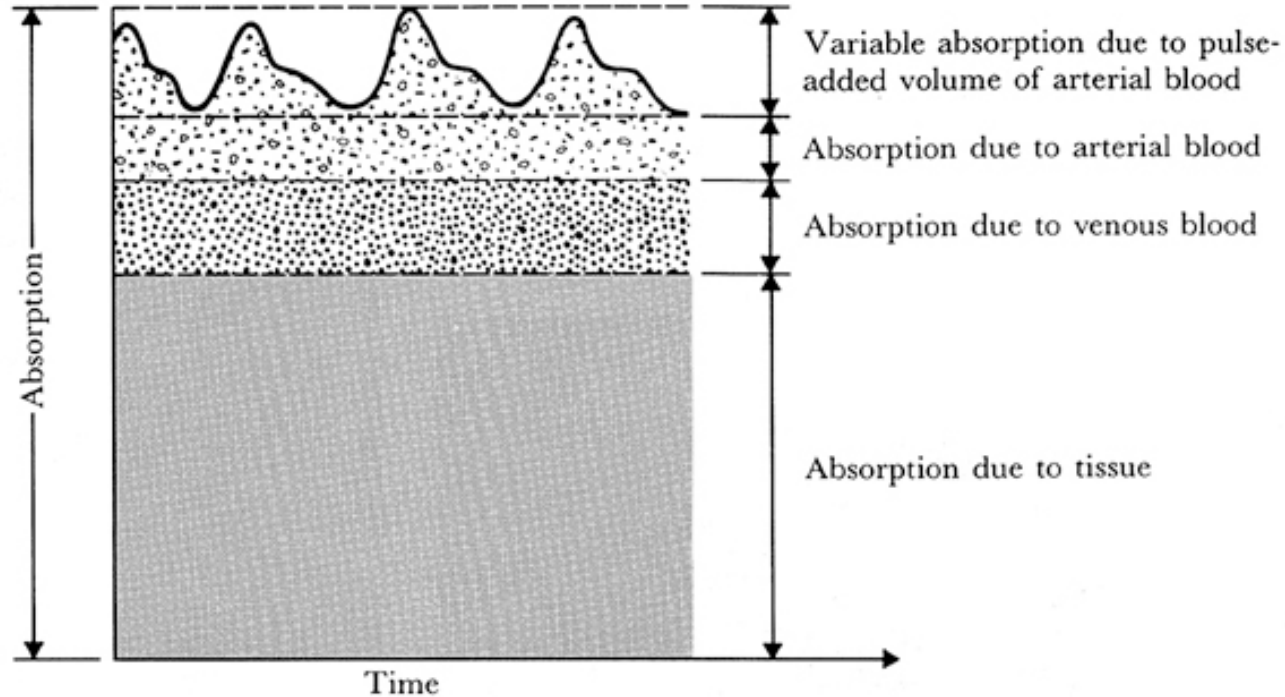


(b) Reflective PPG sensor (rPPG)

Pulse oximetry

- Red/infrared light is not only attenuated by blood
 - Changing part: **the pulsatile flow of arterial blood**
 - Unchanging parts: skin, muscle, fat, venous blood, bone,...
 - Measuring SpO₂ of arterial blood
- Avoid the interference of ambient illuminance

Pulse oximetry





Photoplethysmography (PPG)

- The optical method to measure volumetric change of blood in peripheral circulation.
 - Cardiac pulsation
 - **Heart rate** can be obtained by the cardiac cycle
- It works with only one wavelength
 - Commonly used in wearable devices



生醫工程導論：呼吸系統的生理訊號

Reference chapters:

Chapter 9: Measurement of the respiratory system, “Medical Instrumentation: Application and Design”, John G. Webster.

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