CAIRO UNIVERSITY

MEDICAL EQUIPMENT (1)
TOPIC 1: RECORDING AND PROCESSING OF BIOSIGNALS

Term 1 – 2013/14

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Measurement Basics

- Measuring is the experimental determination of a measured value by quantitative comparison of the measurand with a comparison value in a direct or indirect manner
- Measured value obtained by this procedure is given as a product of a numeric value and a dimensional unit
- It can be recorded continuously as a temporal variation of a physical value or discontinuously at particular moments
- Deviation of measured value from the measurand is the measurement error
  - Depends on measurement procedure, measurement device, and environmental effects
  - Systematic and random errors are distinguished

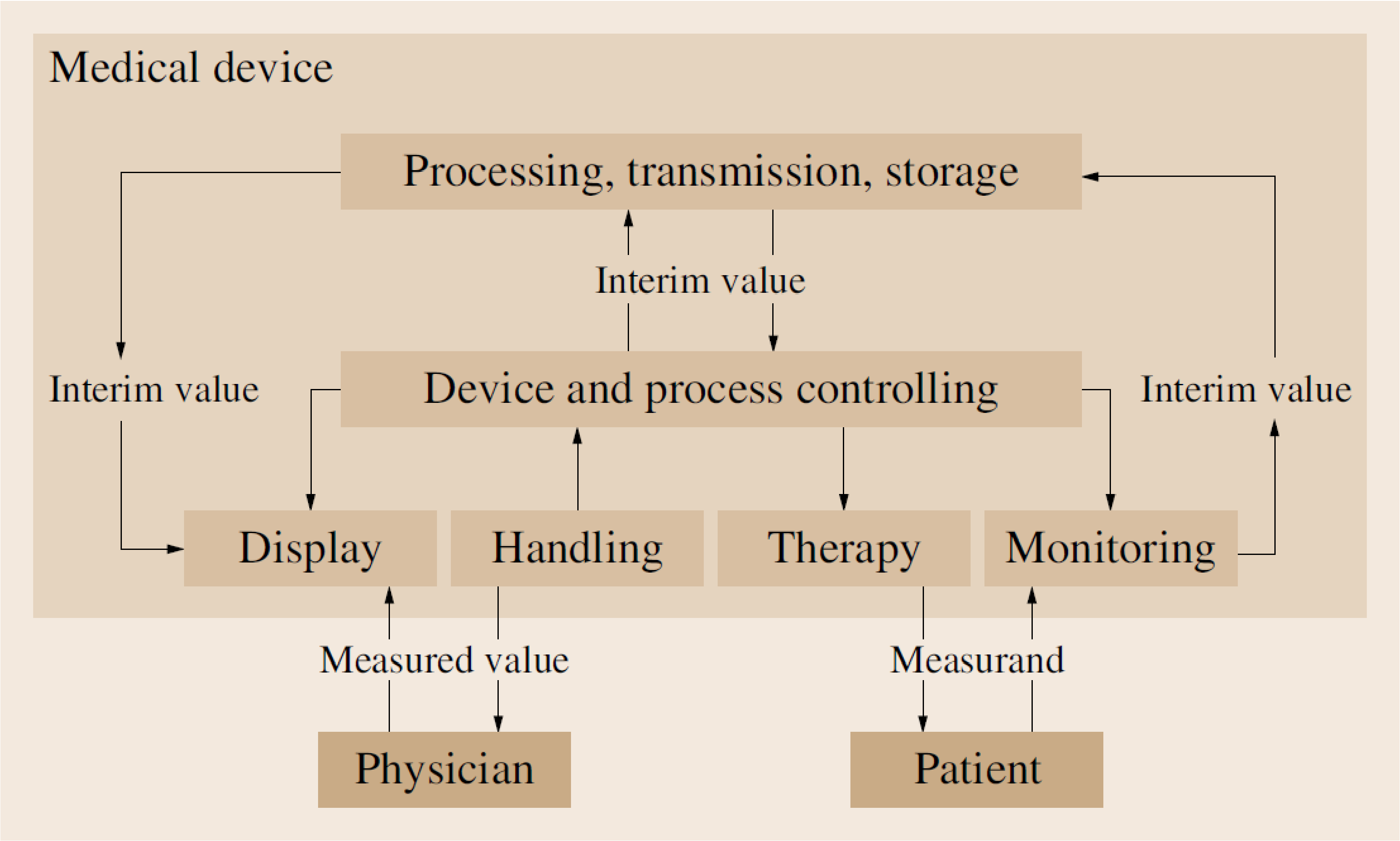
Measuring in Medicine

- Aim of measuring in medicine is objective description of state of patient who might possibly not be able to cooperate
- Goal is to help the physician to define the respective therapy and to evaluate the therapy process and assess the prognosis
- Long-term monitoring of physiological parameters is combined with an alarm function if preset limiting values are exceeded
- New developments include closed-loop systems which directly intervene in patient’s state after analysis of measured values
- Unique in having inter-individual and intra-individual deviations for biological measurements, owing to biological variability
  - Measured values vary from patient to patient and within same patient

Objectives

- Metrological acquisition, conversion, processing and transmission of biological signals
- Measuring the reaction or the behavior of the biological object to an external stimulus
- Measurements during application of extra- or intracorporeal assist systems to support organ functions or as organ compensation, as well as manipulators for therapeutic means
- Application of substances, irradiation or waves and measurement of reflection, absorption, scattering, distribution or fluorescence to display structures and functions in the organism
- Extraction of body fluids, substances and tissues, as well as tests and analysis in clinical and chemical laboratories

Model


Medical device
Processing, transmission, storage
Interim value
Interim value
Device and process controlling
Interim value
Display
Handling
Therapy
Monitoring
Measured value
Measurand
Physician
Patient

Unique Aspects

- Extent of inconvenience for patient and measurement procedure directly influences the reliability of measured values
- Biological sources of interference (biological artifacts with physiological origin) superimposing the measurand
- Measurement duration and the reproducibility of an examination are limited for most methods
- Wide variability of examined persons
  - Ranging from fetus, infants and trained athletes to aged people
- Include subjective methods requiring cooperation of patient
  - e.g., audiometry, vibration tests and temperature sensation

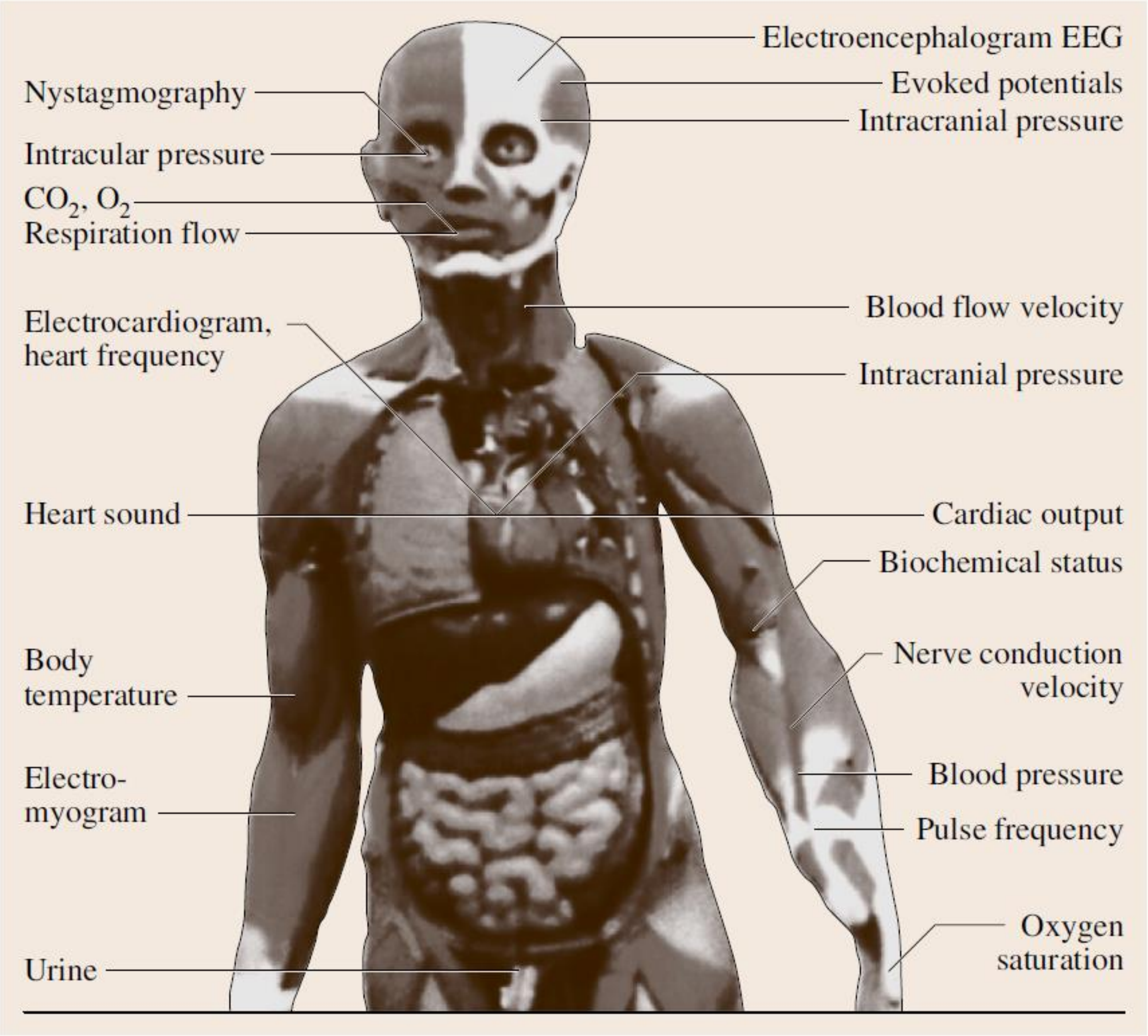
Biosignals

- Biosignals can be defined as phenomena to describe functional states and their variations in a living organism
  - Actual measurand that should be metrologically determined for diagnostic purposes
- Provide information about metabolic, morphological and functional changes, describe physiological and pathophysiological states as well as process dynamics
- To analyze them, generation locus and thus spatial and temporal correlation is significant
- Biosignals are acquired from living organisms, organs and organ parts down to single cells

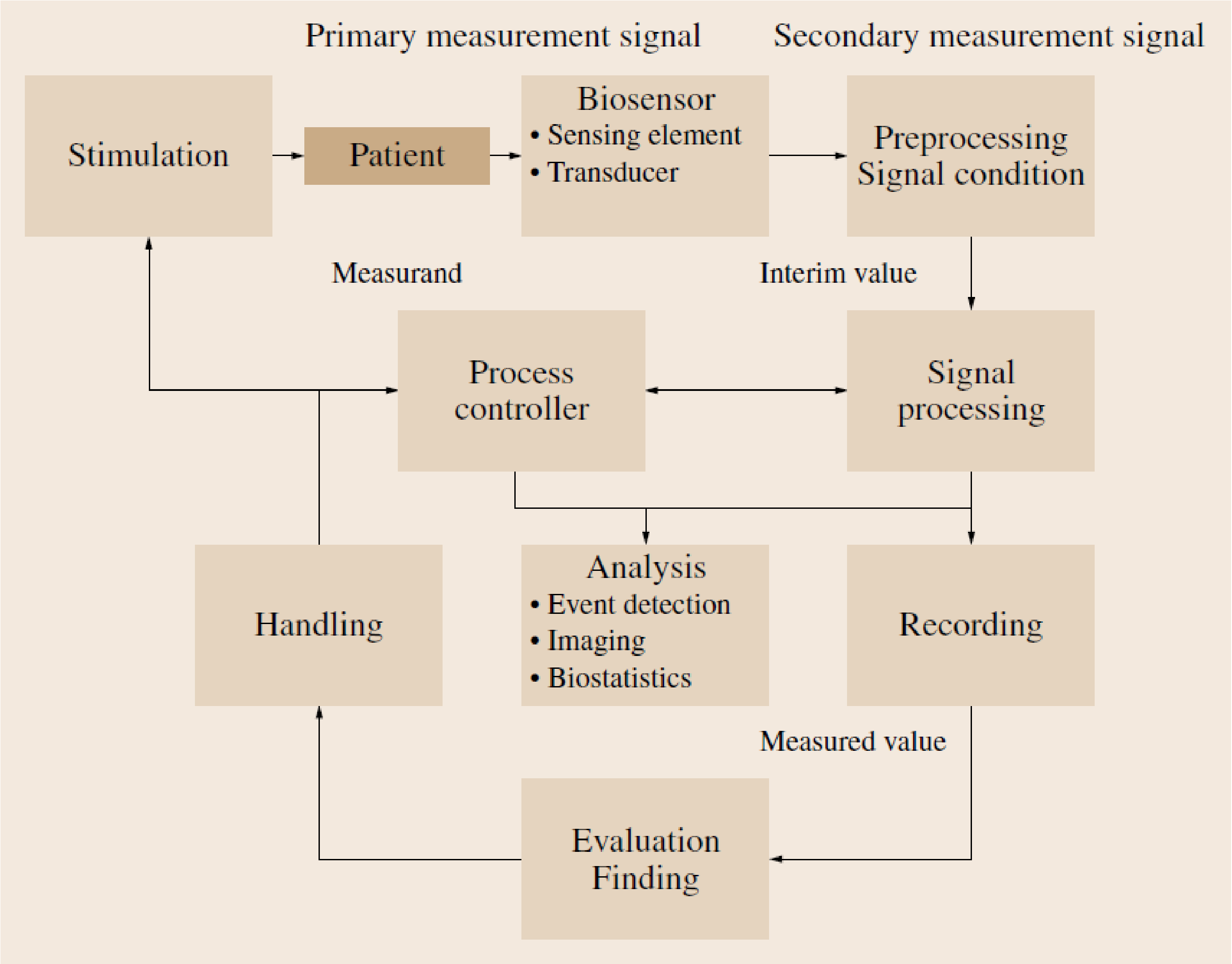
Biosignal Types

- Bioacoustic signals (heart sound, lung sounds, speech)
- Biochemical signals (substance compositions, concentrations)
- Bioelectric and biomagnetic signals (electric potentials, ion currents)
- Biomechanical signals (size, shape, movements, acceleration, flow)
- Biooptical signals (color, luminescence)
- Biothermal signals (body temperature)

Biosignal Examples

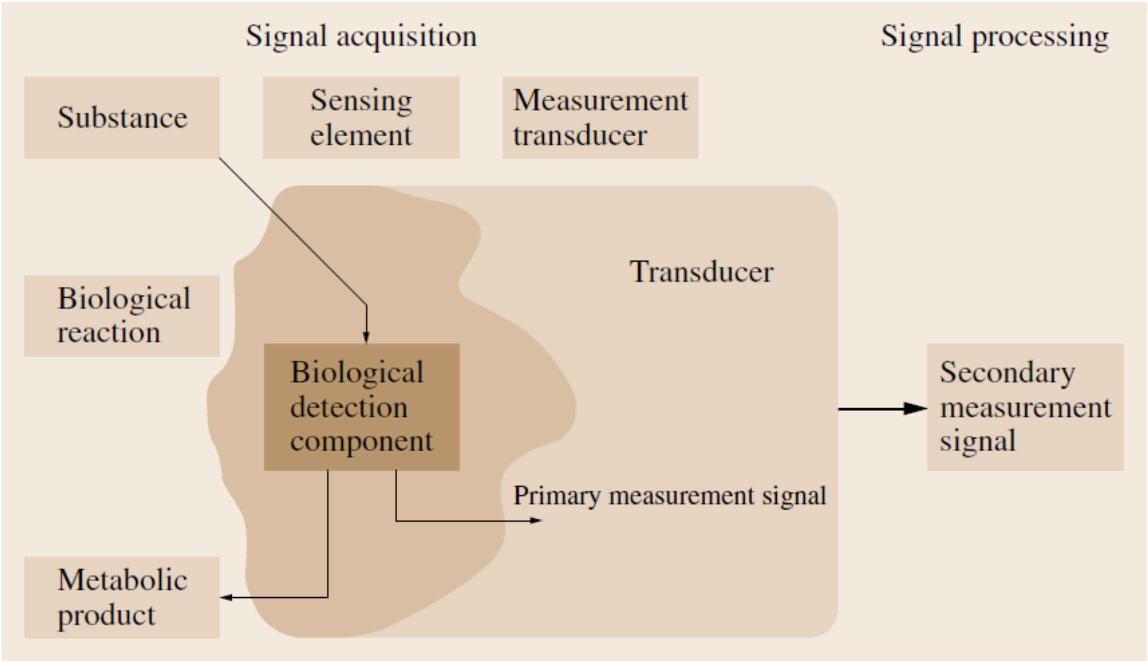


Biological Measuring Chain



Biosensor

- Biosensor is a probe to register biological events and morphological structures
- Often, it is directly connected to a transducer, or it transduces the primary measurement signal into a secondary signal itself

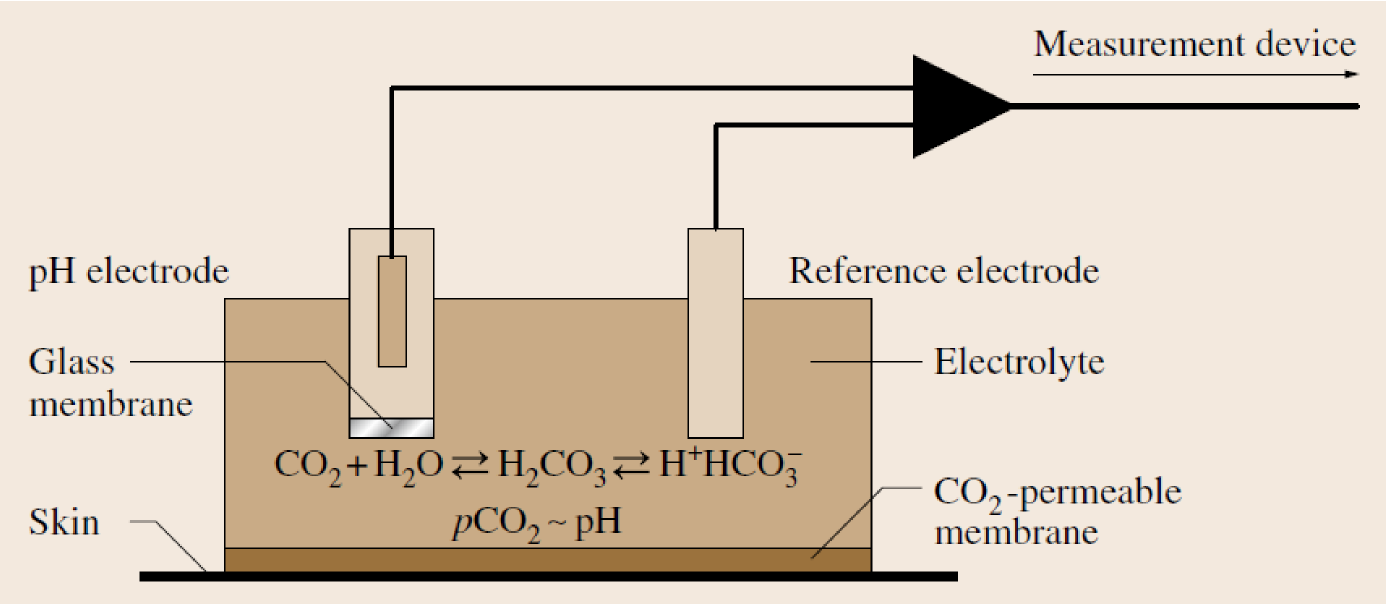


Biosensor Requirements

- Feedback-free registration of the signals
- Provide reproducible measurement results
- Transmission behavior has to remain constant for a long time
- Narrow production tolerances
- High biocompatibility
- Low stress to patient
- Small mass and small volume
- Application should be simple and manageable
- Allow cleaning, disinfection and possibly sterilization

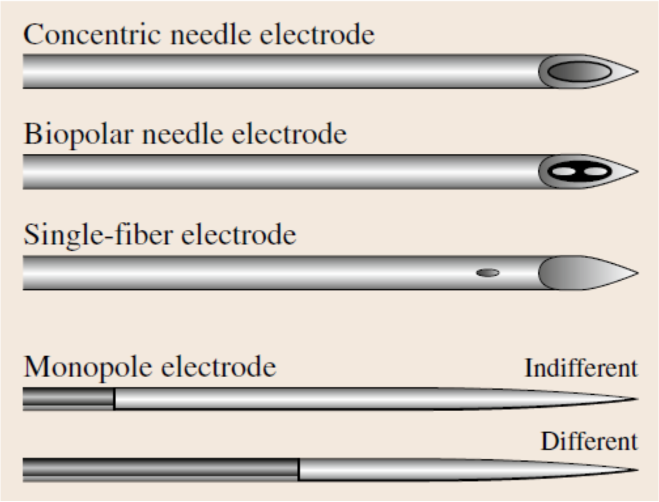
Chemoelectric Transducers

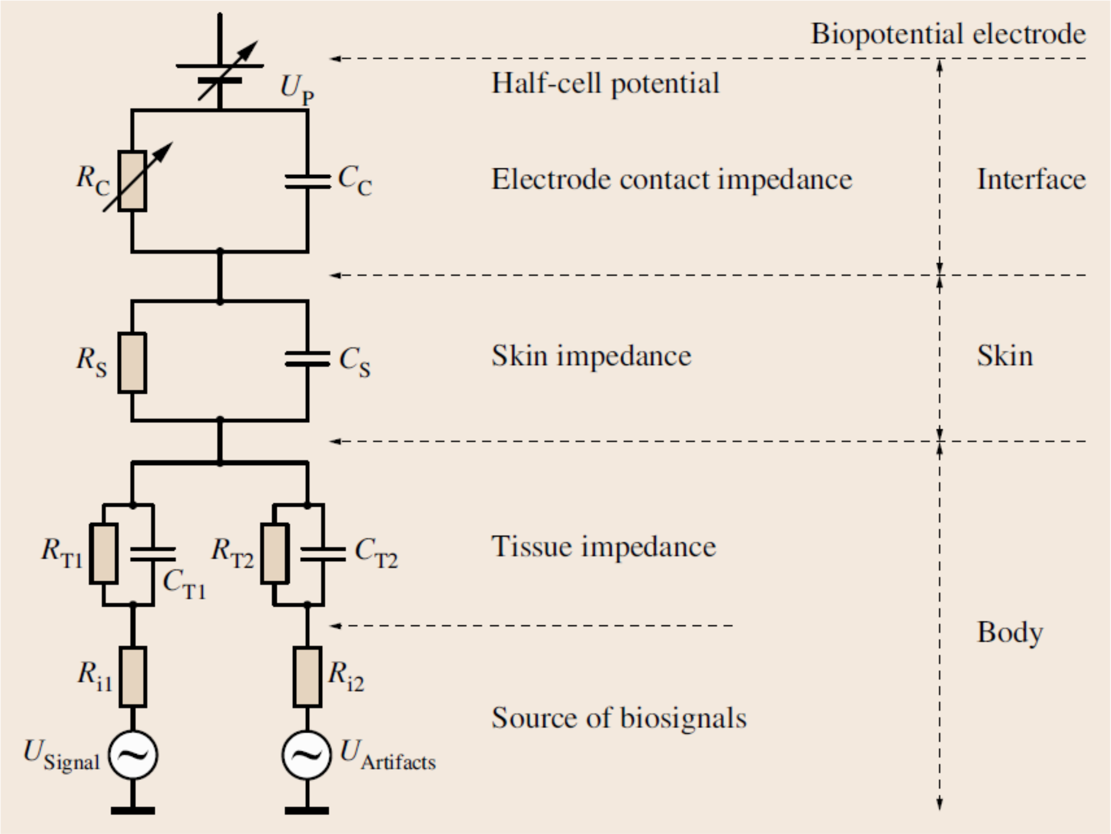
- Used for the measurement of individual chemical components in the blood, in body tissues, in the exhaled air or on the skin
  - Potentiometric sensors, based on the measurement of cell potential
  - Amperometric sensors, based on cell current
  - Conductometric sensors, based on admittance



Electric and Magnetic Transducers

- Transduce electric signal (ion current) into electric signal (electron current)
- Two groups: microelectrodes (metal microelectrodes) and macroelectrodes (surface electrodes)





Mechanoelectric Transducers

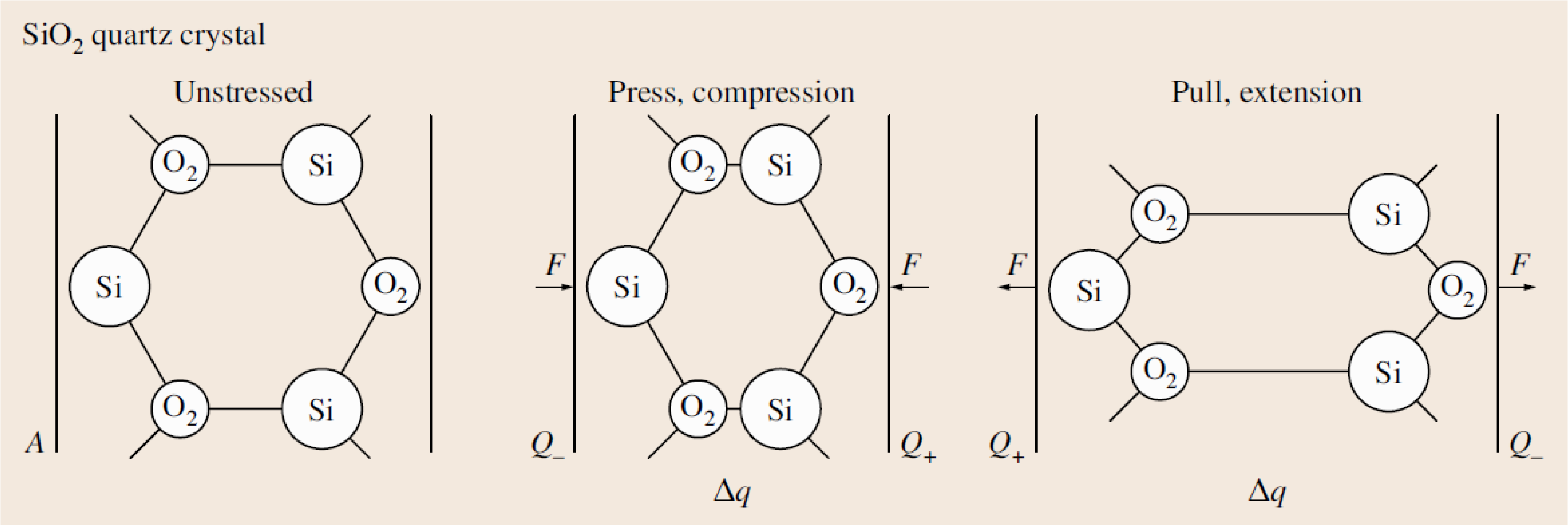
- Measure length changes, strains, pressure changes in tissue, body fluids and organs as well as for the measurement of sounds, microvibrations and blood flow
- Strain Gauge: $R=\rho L/A$ allows detecting changes in L
- Piezoresistive elements as strain gauge in a Wheatstone bridge
  - Changes in resistivity can be observed that are up to 100 times larger than the geometric effect yielding a more sensitive strain gauge
- Capacitive transducer: force applied to capacitor yielding a change in the distance between its two plates changes C

$$C_X = \varepsilon_0 \varepsilon_\gamma \frac{A}{x}$$

Mechanoelectric Transducers

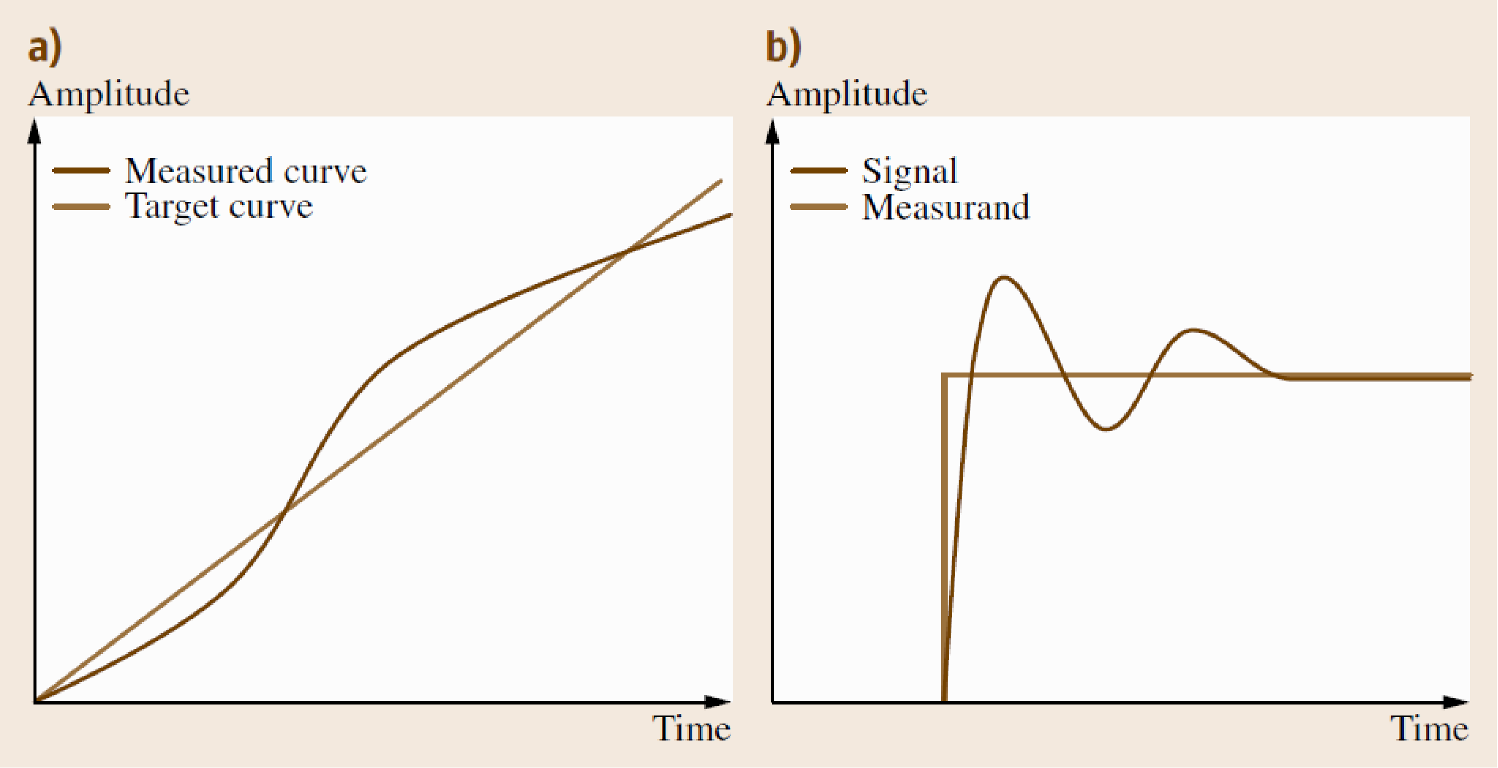
- Piezoelectric transducers: Mechanical stress in the direction of a polar electric axis causes the generation of electric charges due to a shift of the atoms, at very small deformations

$$\Delta q = k \Delta F$$



Dynamic Properties of Biosensors

- Ideal transmission behavior of a measuring chain is linear
  - In reality, relation is not linear, delayed and sometimes oscillating
- Signal processing is to correct for such problems



Bioacoustic Signals

- Includes sounds of the upper respiratory tracts (snoring, speech), lung sounds and heart sound
- Can be registered with a microphone or a stethoscope

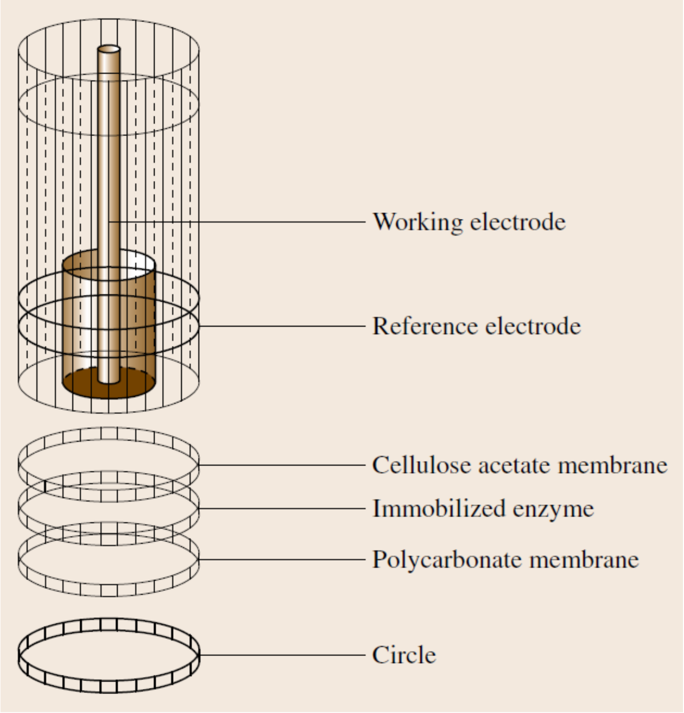
Signal	Specification	Frequency (Hz)
Heart sound	Adults	15–1000
	Fetus	15–150
Lung		0.2–10

Biochemical Signals: Glucose

- Can be determined *in vivo* or *in vitro*
- They can be registered directly or indirectly by reaction
- Example: Glucose identification
  - Amperometrically detected by the O_2 consumption or the hydrogen peroxide formation

$$\text{Glucose} + O_2 \xrightarrow{\text{GOD}} \text{Gluconolactone} + H_2O$$

$$\xrightarrow{H_2O_2} \text{Gluconic acid} + H_2O_2$$

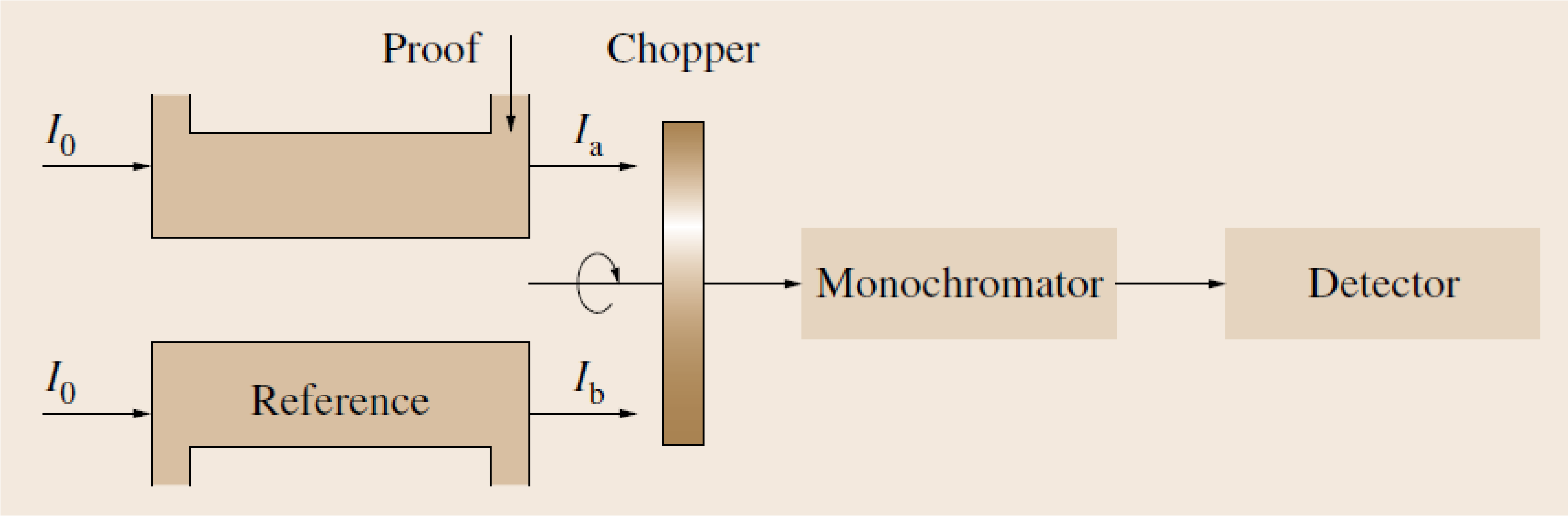


Biochemical Signals: Concentration

- Infrared spectrometers measure the intensity attenuation of infrared radiation after passing a measuring cuvette and compare it with a reference

$$I_a = I_0 e^{-kcl}$$

  - I_a :output intensity, I_0 :input intensity, c :concentration, l :layer thickness, and k :constant of proportionality



Bioelectric and Biomagnetic Signals

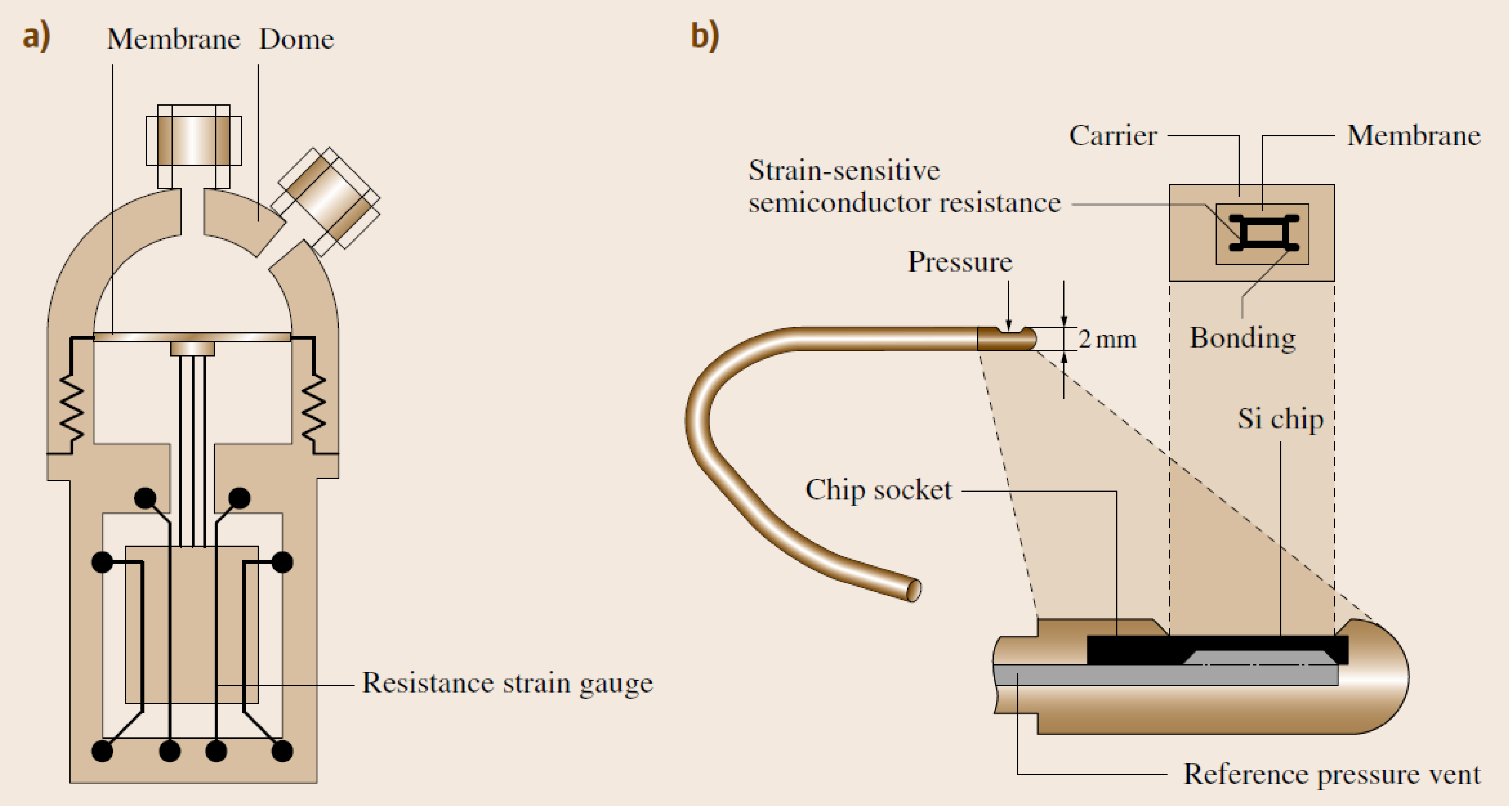
Signal	Frequency (Hz)	Amplitude (mV)
ECG (heart)	0.2–200	0.1–10
EEG (brain)	0.5–100	2–1000 μV
EMG (muscle)	10–10 000	0.05–1
EGG (stomach)	0.02–0.2	0.2–1
EUG (uterus)	0–200	0.1–8
ERG (retina)	0.2–200	0.005–10
EOG (eye)	0–100	0.01–5
FAEP (brain stem)	100–3000	0.5–10 μV
SEP (somatosensory system)	2–3000	0.5–10 μV
VEP (visual system)	1–300	1–20 μV

Biomechanical Signals

Signal	Spezification	Amplitude	Conversion
Pulse (rate)		720–200 min^{-1}	
Breathing (rate)		5–60 min^{-1}	
Blood pressure (arterial)	Systole	8–33 kPa	60–250 mmHg
	Diastole	5–20 kPa	40–150 mmHg
Blood pressure (venous)		0–4 kPa	0–30 mmHg
Intraocular pressure		0–7 kPa	0–50 mmHg
Blood flow		0.05–5 l/min	
Blood flow velocity		0.05–40 cm/s	
Respiratory flow velocity		20–120 cm/s	
Cardiac output		3–8 l/min	
Respiratory volume		200–2000 ml/gasp	
Muscle work		10–500 W	
Blood volume	Adults	7000 ml	
Amount of urine	Adults	1500 ml/d	
Nerve conduction velocity	Median nerve	50–60 m/s	

Biomechanical Signals: Pressure

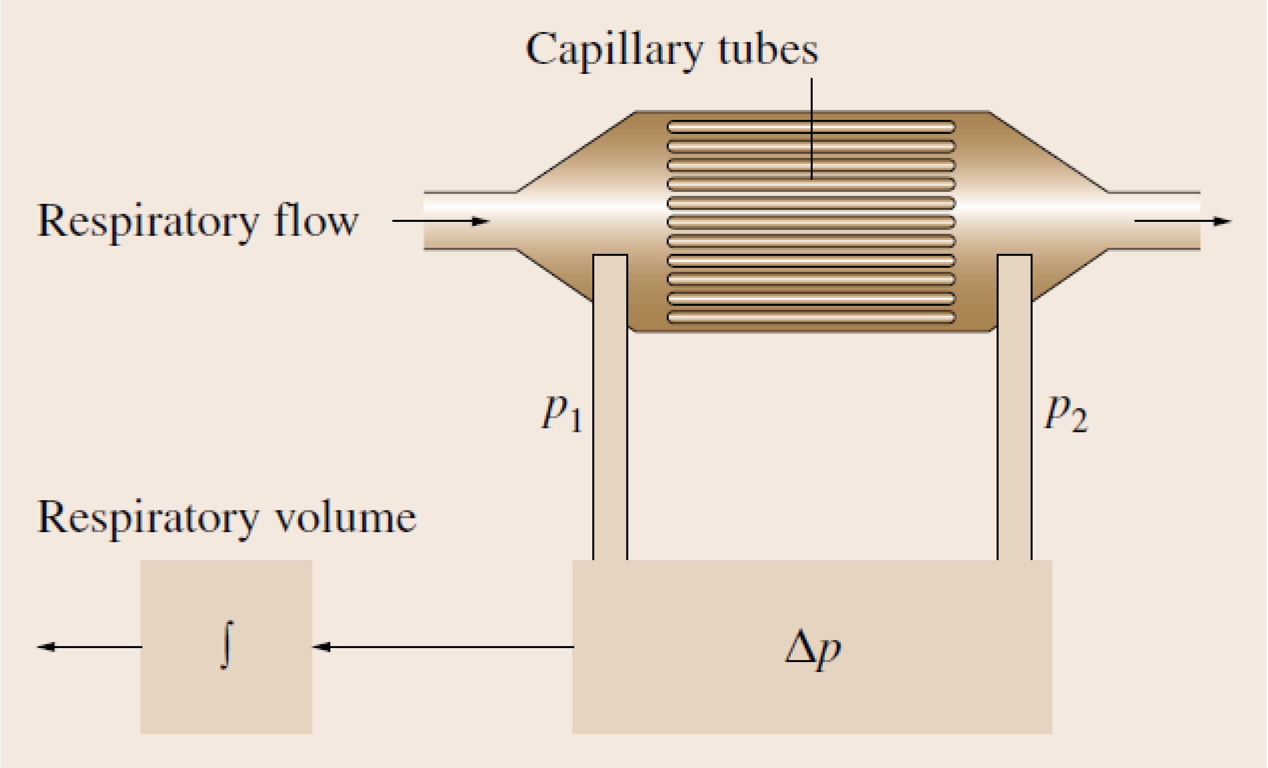
- IBP: Invasive probe



Biomechanical Signals: Volume

$$\dot{V} = \frac{\pi r^4 \Delta p}{8 l \eta}$$

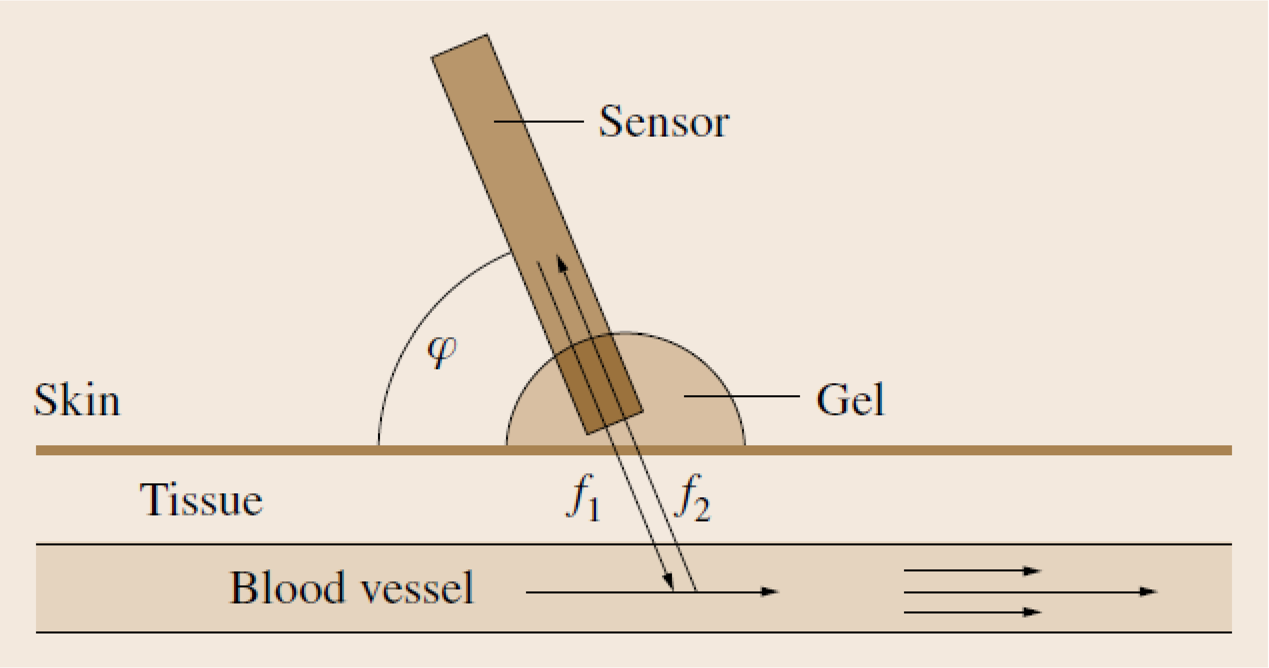
$$V = \int_0^t \dot{V} \, \mathrm{d}t$$



Biomechanical Signals: Flow Velocity

- Doppler effect

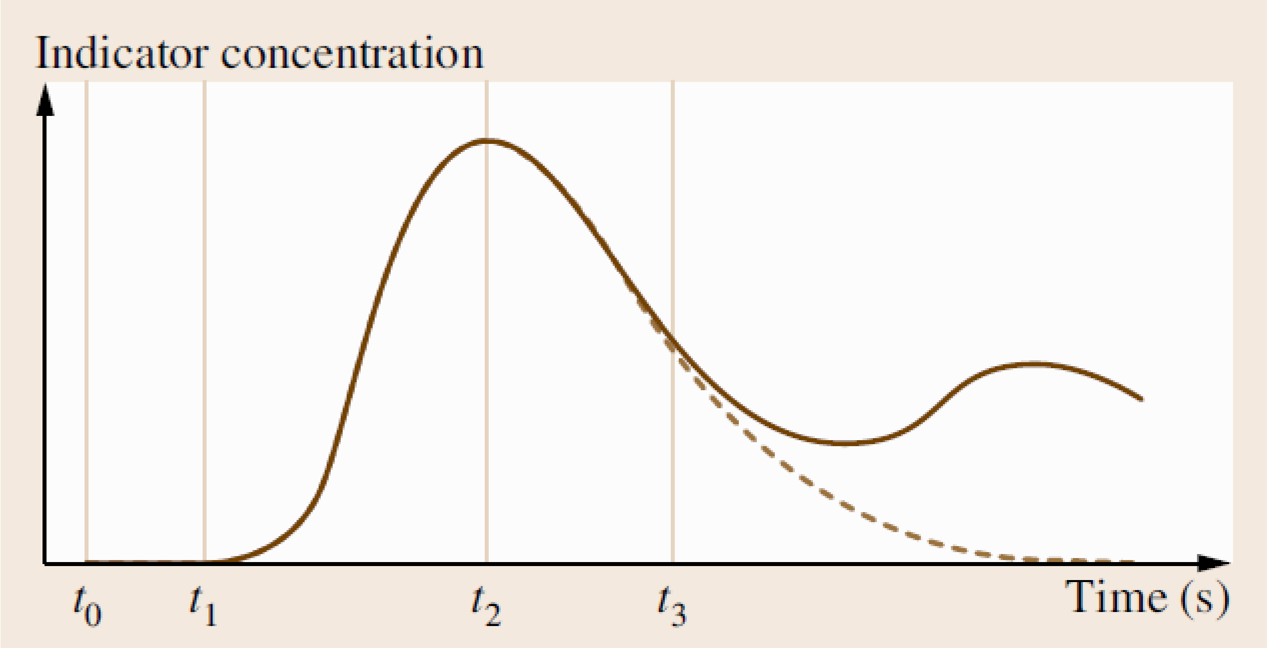
$$\Delta f = f_1 - f_2 = f_1 \frac{2v \cos \varphi}{c}$$



Biomechanical Signals: Cardiac Output

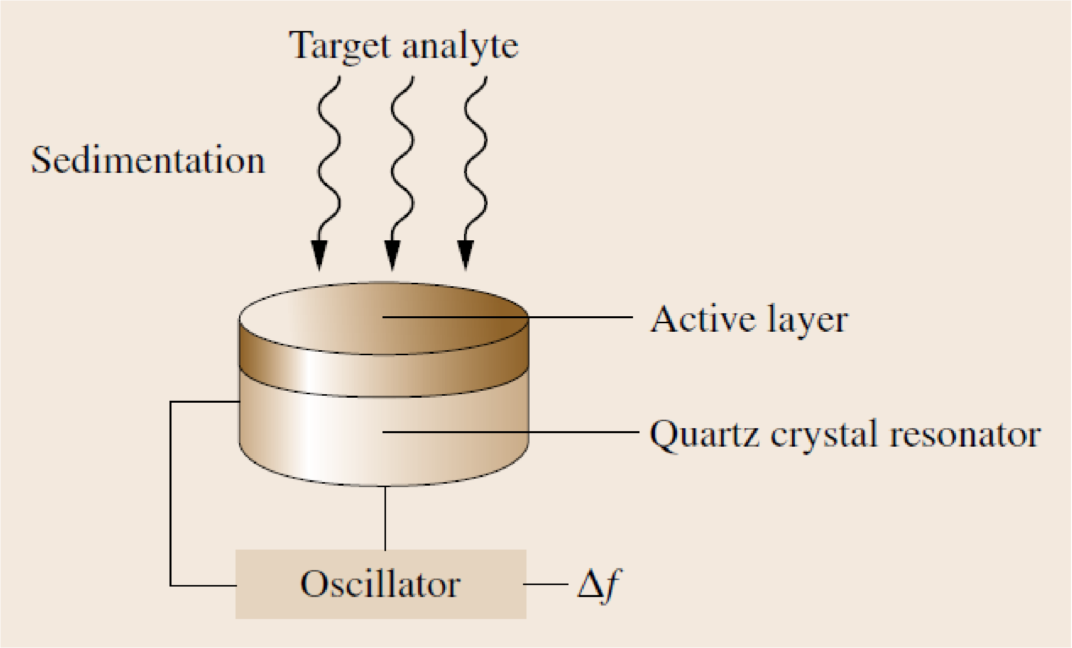
- Indicator-Dilution method

$$CO = \frac{m_0}{\int_{t_0}^{\infty} c(t)\, dt}$$



Biomechanical Signals: Mass

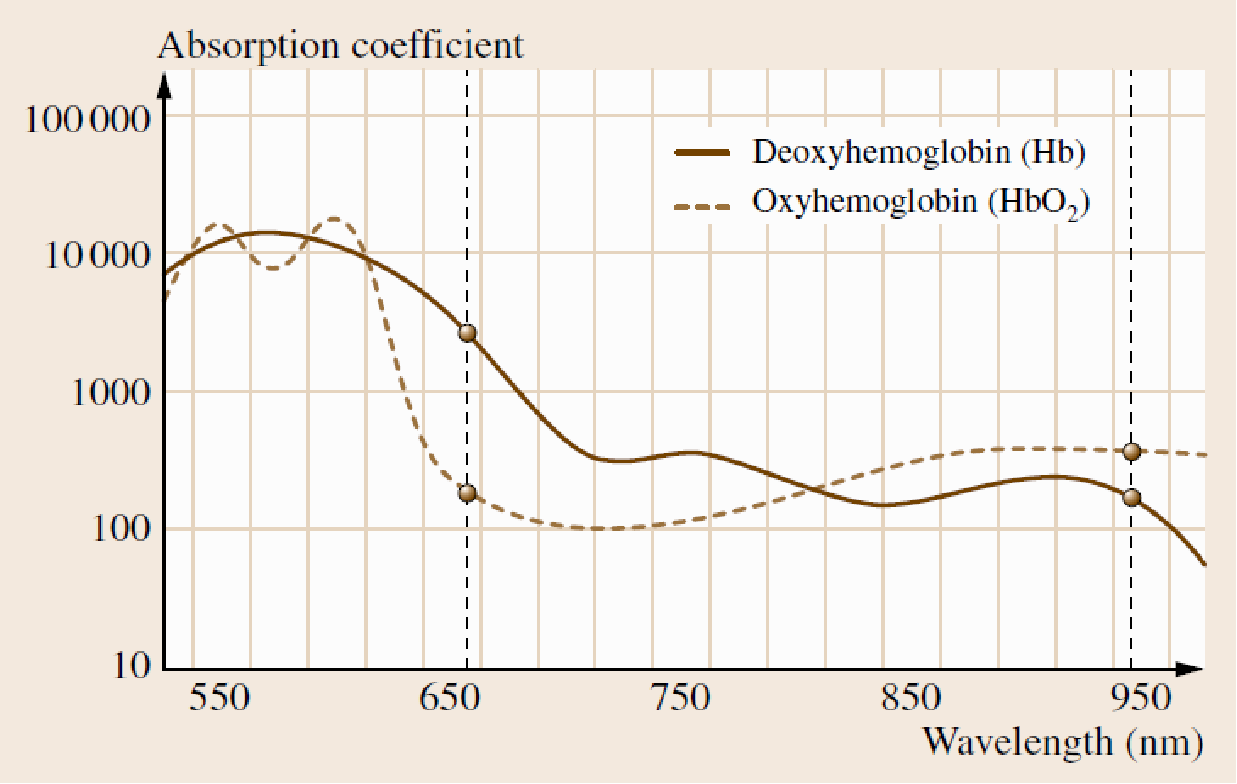
- Quartz microbalance
  - measurement is based on resonance frequency shift of an oscillating crystal due to deposition of substances on the crystal surface



$$\Delta f = \frac{2.3 \times 10^6 f_0^2 \Delta m}{A}$$

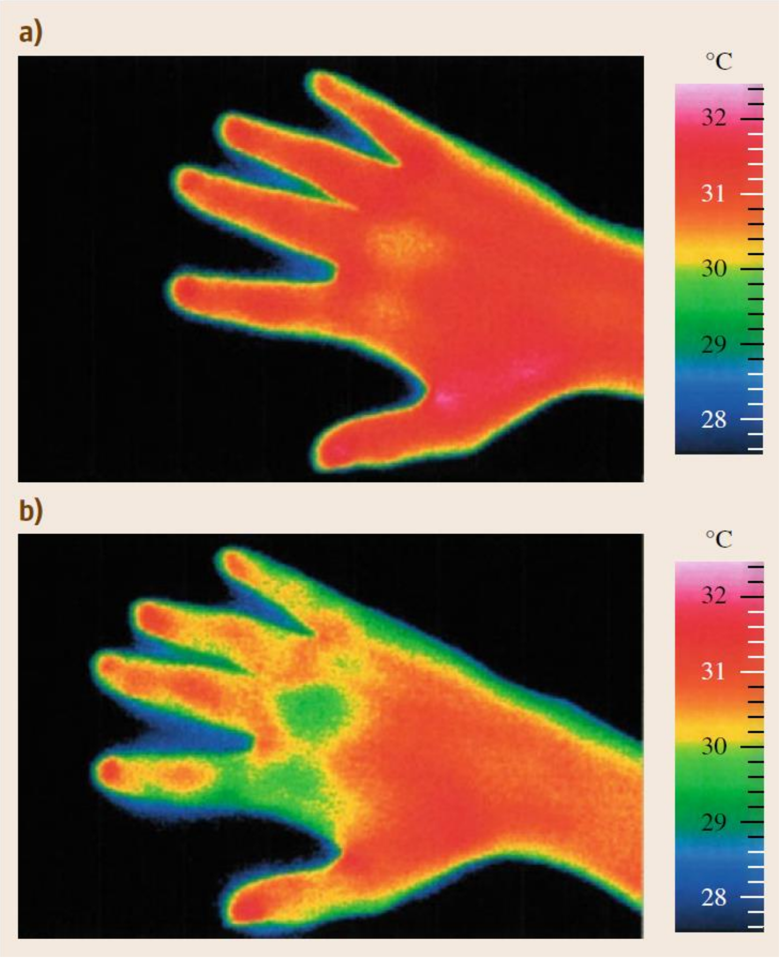
Biooptical Signals: O_2 Saturation

- Evaluation of color (skin)
- Evaluation of O_2 saturation based on the different absorption characteristics of oxygenated and deoxygenated hemoglobin



Biothermal Signals: Thermography

- The Most important biothermal signal is the body temperature
- Using thermography, temperature distribution on a skin area can be determined.
- Pathological changes can be detected from distribution relative to normal areas
  - Example: reduction of blood flow due to smoking



Assignments

- Sheet #1 on class web site