Development of Complex Curricula for Molecular Bionics and Infobionics Programs within a consortial* framework**

Consortium leader

PETER PAZMANY CATHOLIC UNIVERSITY

Consortium members

SEMMELWEIS UNIVERSITY, DIALOG CAMPUS PUBLISHER

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**Molekuláris bionika és Infobionika Szakok tananyagának komplex fejlesztése konzorciumi keretben

***A projekt az Európai Unió támogatásával, az Európai Szociális Alap társfinanszírozásával valósul meg.

ELECTRICAL MEASUREMENTS

(Elektronikai alapmérések)

Basics of biological and medical measurements

(Biológiai és orvosi mérések)

Dr. Cserey György

Systole and diastole - blood pressure

Systolic blood pressure: when the heart contracts and pumps blood to the vascular system. (Normal value: 140 Hgmm)

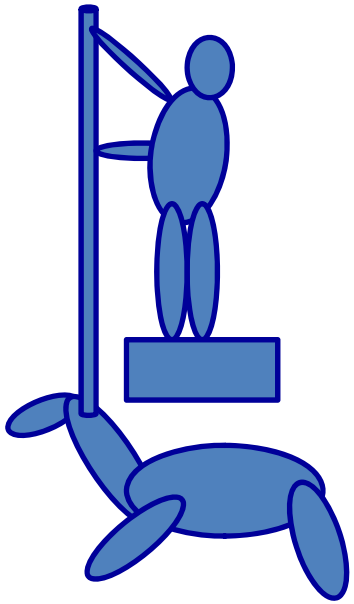
Diastolic blood pressure: the pressure can be measured in a blood vessel at the relaxation of the heart. (Normal value: 80-90 Hgmm)

Cardiac (heart) contractions causes the blood pressure on the walls of blood vessels, which is greater in the artery, smaller in the veins. The pressure on the wall of the veins is the blood pressure.

The proper blood pressure is needed to push the blood to reach different parts of the body, and each organ should receive appropriate amount of blood.

Measuring blood pressure - invasive

- In 1733 Stephan Hales, to measure blood pressure, connected a vertical 340 cm glass tube to the metal canulla in a horse's carotid artery, then he measured the height of the blood in the tube (290 cm).
- In 1847 Carl F. W. Ludwig german physiologist measured human blood pressure with his "kymograph".

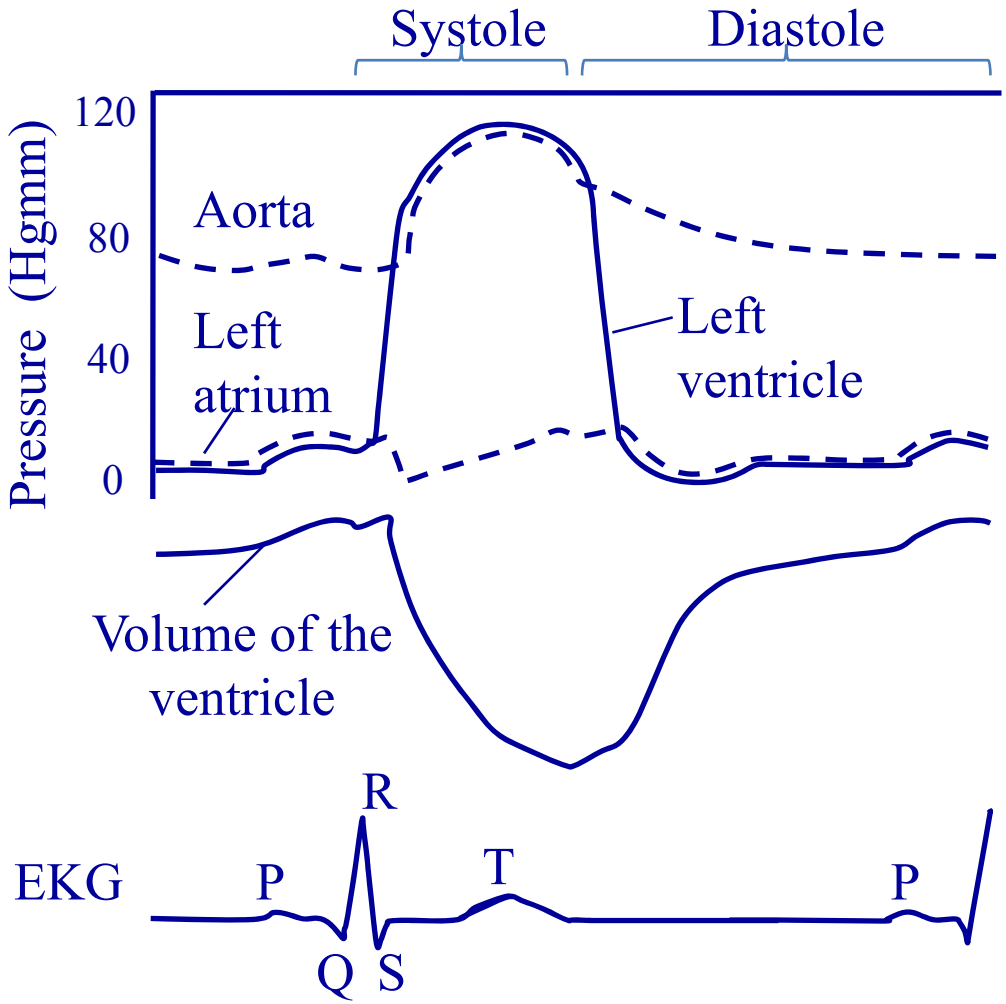


Measuring blood pressure – non-invasive

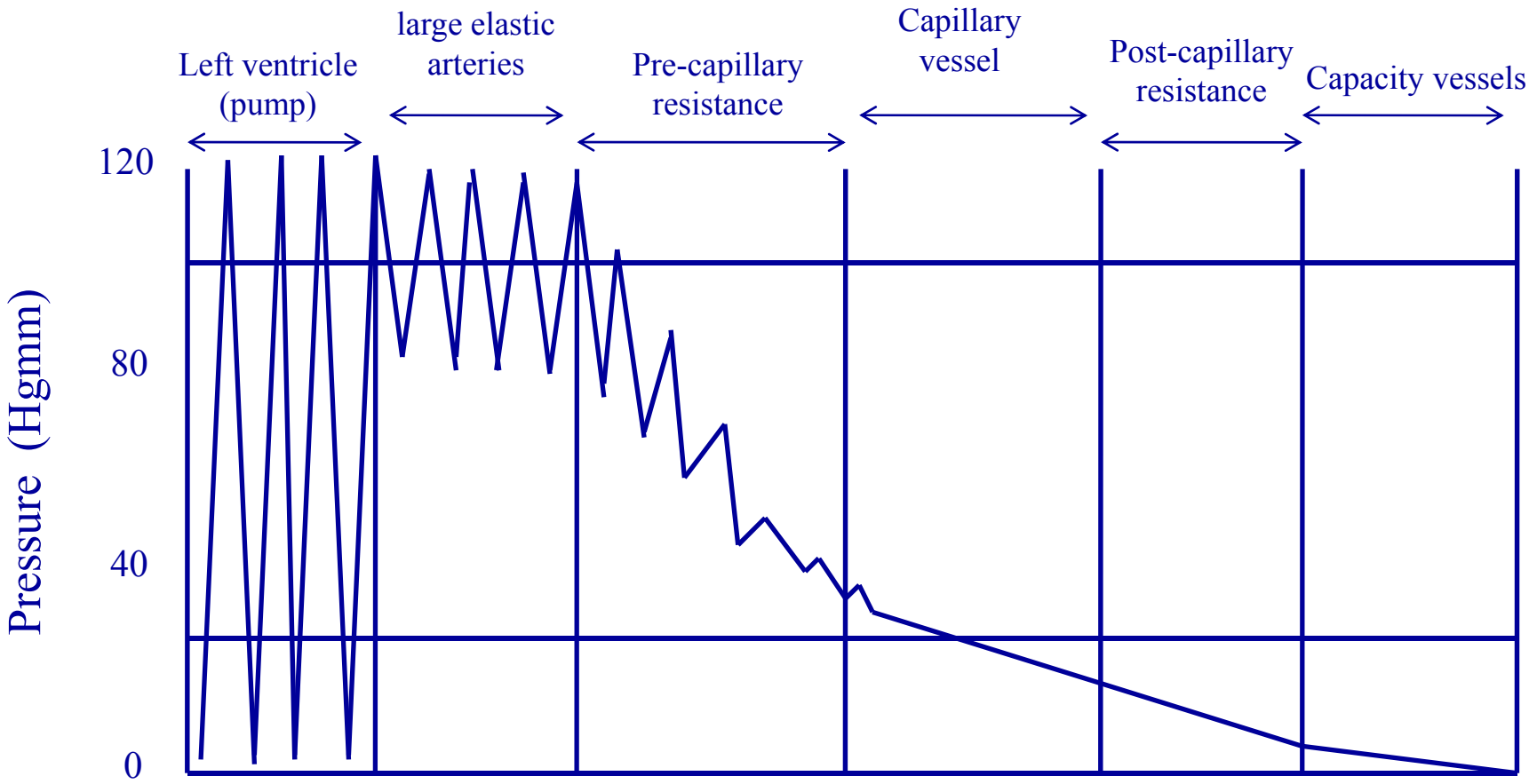
- Scipione Riva-Rocci (1896): mercury **Sphygmomanometer**, measuring systole only with touch, the value measured at the disappearing of the pulse equals to the pressure of the fully compressed artery.
- Nyikolaj S. Korotkov (1905): measuring systole and diastole with the help of a stethoscope. He described the characteristic sound of the opening of a blocked artery. The Korotkov sound is created because of the turbulent flow, its appearance correlates with the systolic pressure, its disappearance correlates with the diastolic pressure.

Blood pressure

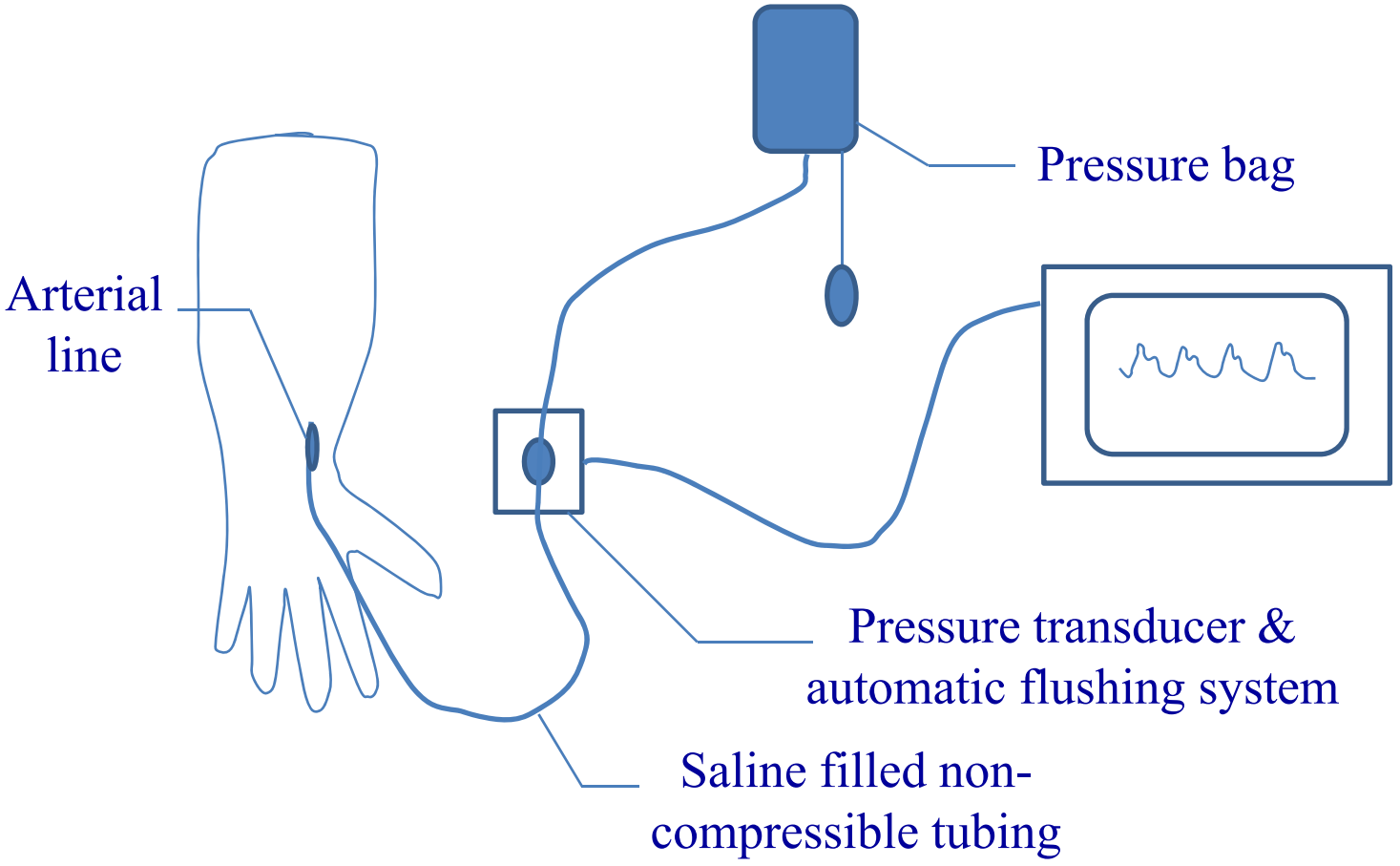
- Systole
- Diastole
- Dysfunctions:
  - Hypertonia
  - Renal failure
  - Aneurysm



Blood pressure

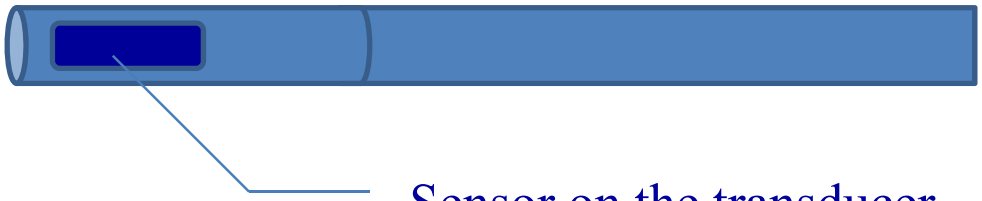


Invasive measurement



Invasive measurement

- Sensor inside the vein.
- It measures at a given point.
- Fewer possibilities of measurement errors, small size.
- It shows high frequency pressure changes. Disadvantage: the transfer characteristic is not perfectly linear



Non-invasive measurement

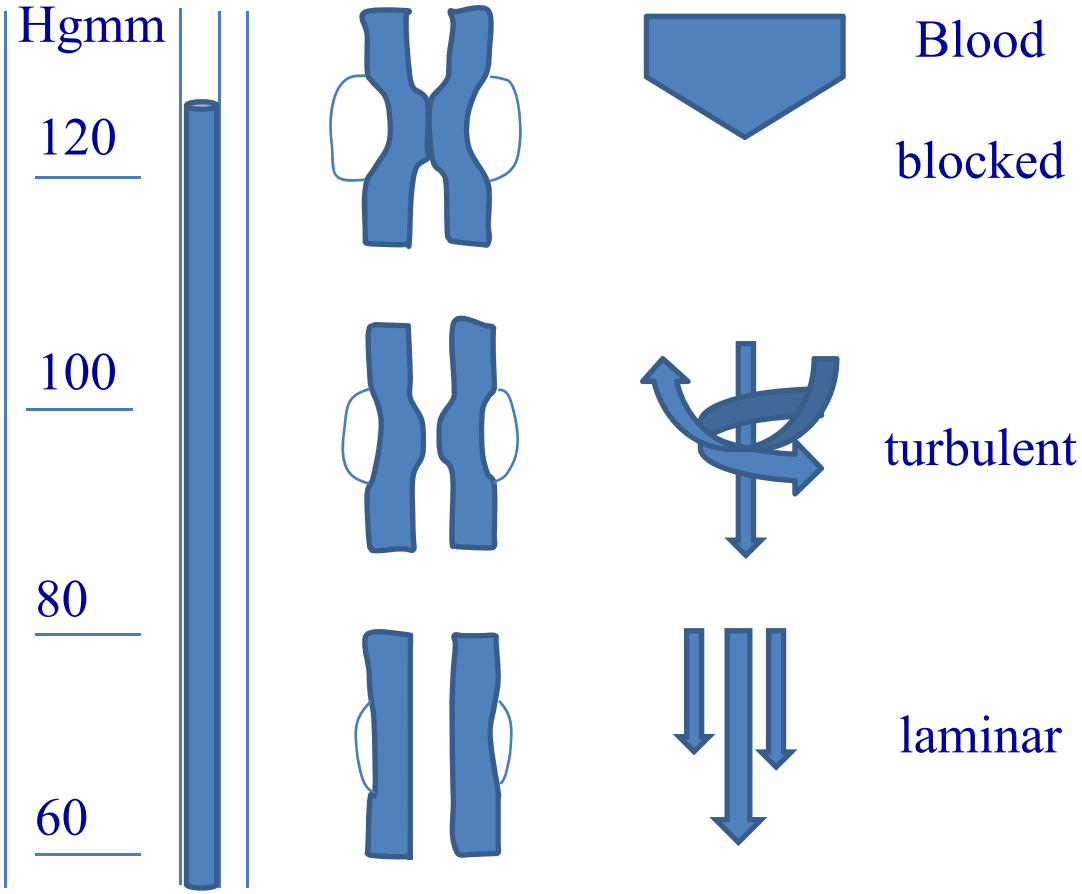
- Riva-Rocci: measuring the pressure of a cuff, when it equals the arterial pressure. During measuring the blood pressure, the cuff is normally placed smoothly and snugly around an upper arm, at roughly the same vertical height as the heart while the subject is seated with the arm supported.
- Non-invasive measurement
- Detecting equality:
  - Monitoring the pulse wave
  - Monitoring the movement of the vascular walls
  - Monitoring Korotkov's sounds
  - Monitoring the oscillometric waves in the cuff

Measuring blood pressure

Indirect method: cuff on the upper arm

- The pressure of the cuff is slowly reduced. Basic idea: When the arterial pressure is bigger than the pressure of the cuff, then blood is flowing in the artery. When the pressure of the cuff is bigger, blood does not flow in the artery.
- There are methodical problems when the pressure of the cuff is reduced too fast.
- Korotkov's sounds: The pressure of the artery is just bigger than the pressure of the cuff. Systole, diastole sounds

Pressure measurement with mercury

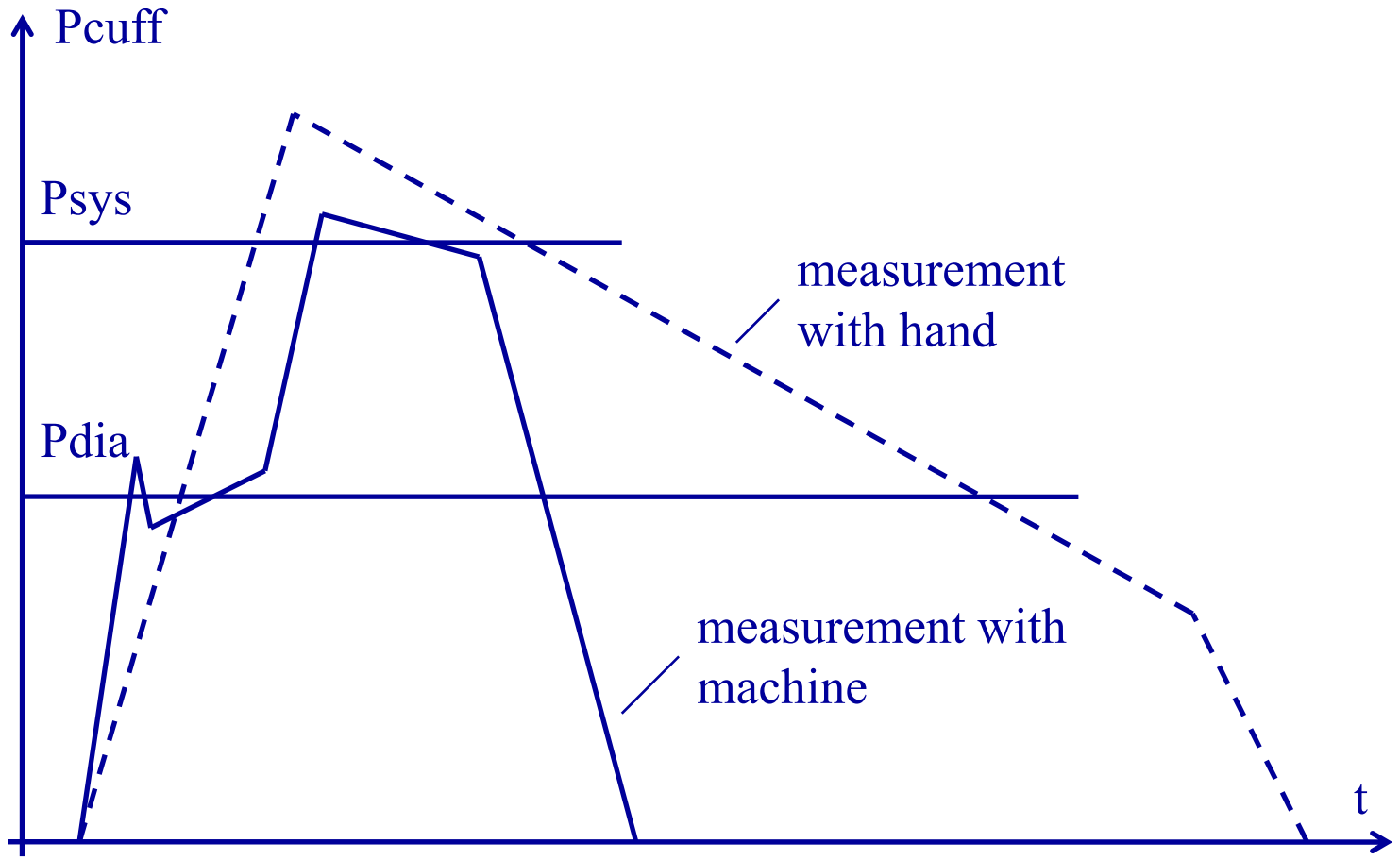


Pressure measurement with mercury

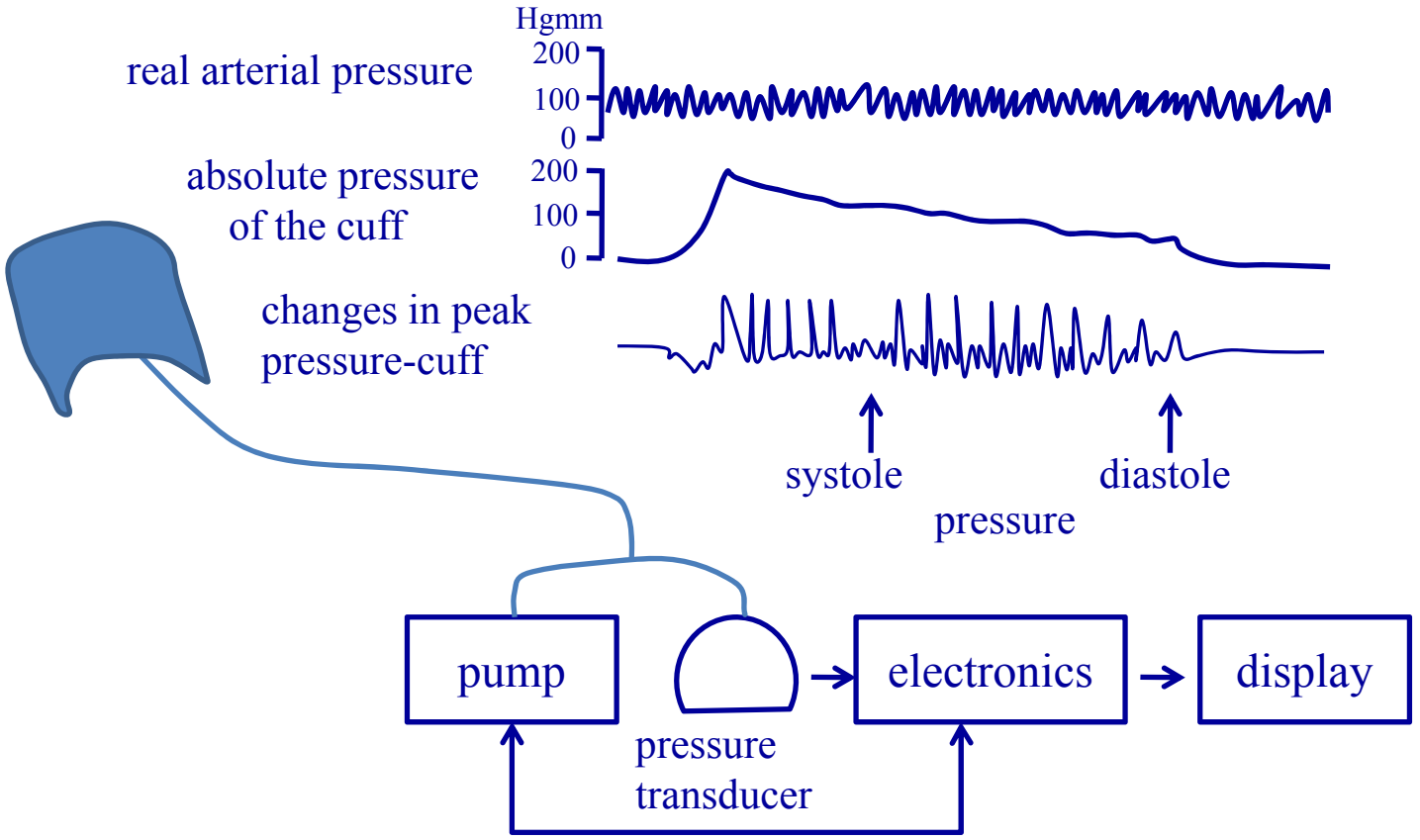
Increasing pressure, higher with 20-30 Hgmm

- Rate of pressure decrease: 2 Hgmm/sec
- I. Sound appears: systole pressure
- Further pressure decrease
- When the sound disappears, it is diastole pressure
- Mercury is a chemical element of the Periodic table. Its chemical symbol is Hg, plate 80. In its elemental form it has the color of silver, of metal, it it liquid, conducts heat and electricity, and evaporates easily, so it should be kept closed.

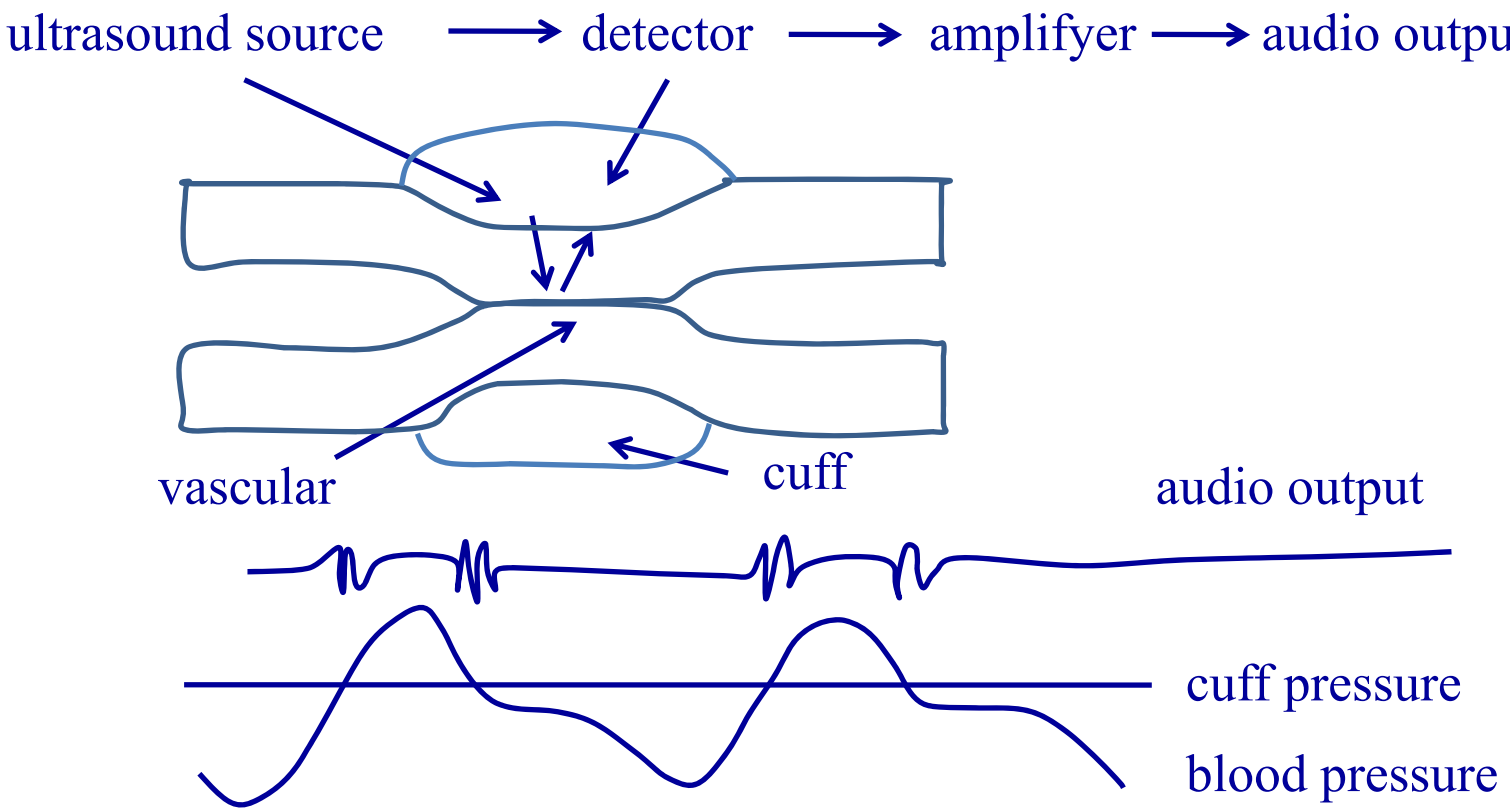
Pressure profile



Oscillotonometry



Blood pressure measurement with ultrasound



Invasive – Non-invasive

- Invasive method: a medical procedure during which the body is penetrated by cutting or pricking.
- Non-invasive method: Not penetrating the body, as by incision or injection

- Continuous measurement
- Etalon measurement
- Pulse curve
- Invasive
- Relatively expensive

- Instantaneous value
- Many error possibilities
- only Psys, Pdia
- Non-invasive
- Cheap

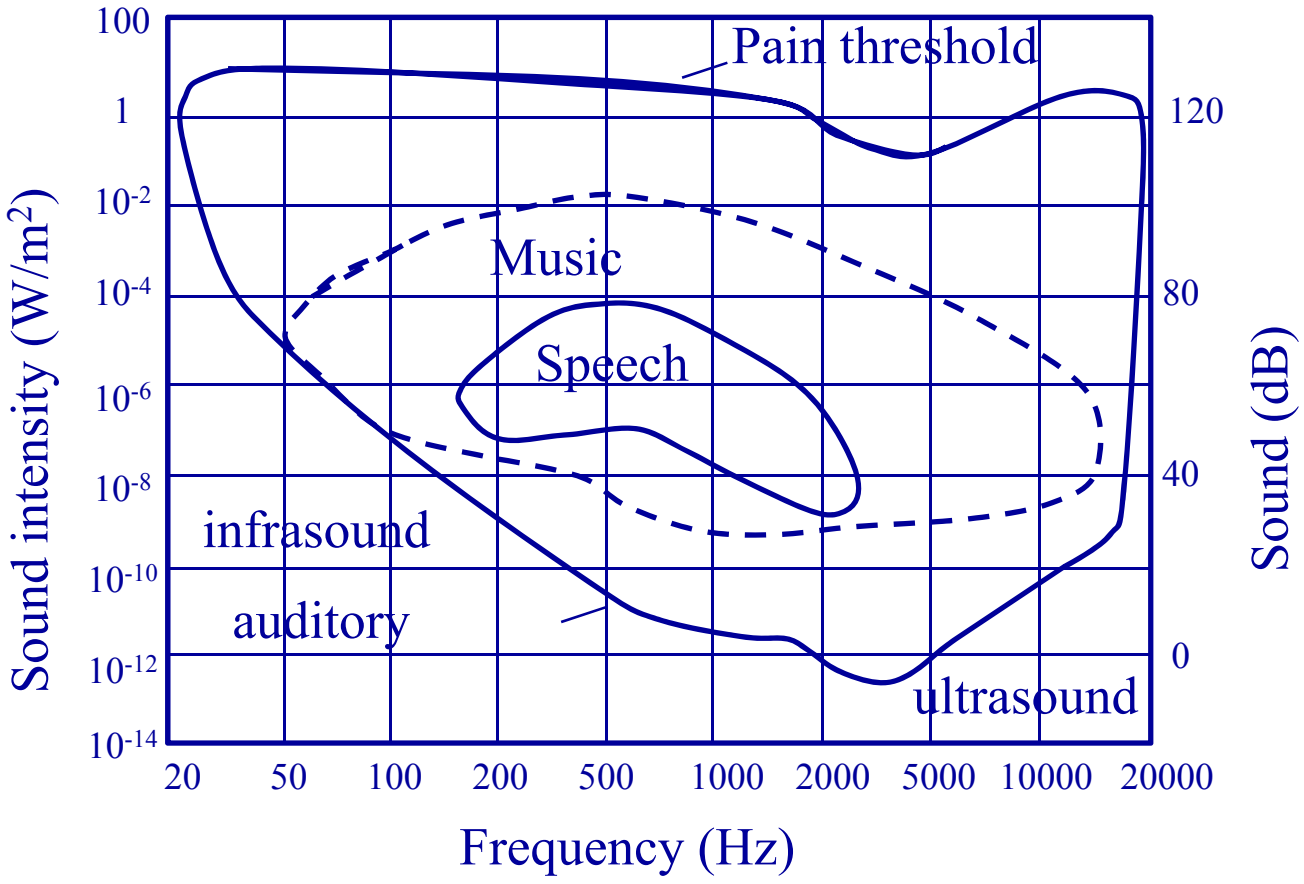
Pulse test

- It is known for centuries
- It was the only objective diagnostic method for many years
- No need for an instrument
- With touch
  - ECG with monitor
  - With the help of an arterial pressure curve
  - Finger-photopletismography. The basic idea is that light can penetrate the network of capillaries, pulsation affects the reflection of light and its scattering

Examination of hearing

- The characteristics of hearing: threshold stimulus, threshold of pain, acoustic resolving ability, direction hearing. All of these depend on frequency.
- During the examination of hearing, it has to be decided if hearing is normal, and if it is not, then the extent of the impairment has to be defined.
- Hearing examinations analyze the whole chain: external ear – external auditory canal – tympanic cavity – acustic/electronic converter – nervus acusticus – hearing center.

Examination of hearing



Examinations demanding cooperation

- Examinations demanding cooperation
- The signal of the oscillator can be transmitted to either of the earphones on either ears, and the volume can be controlled.
- Noise generator
- Microphones make the examination of speech understanding possible.
- The audiometers demanding cooperation give only impulsive signal. The patient gives the sign if he heard the noise.

Examinations demanding cooperation

- György Békésy
- An audiometer is a machine used for evaluating hearing loss.
- The patient gives a sign with the help of a switch when he hears the noise. If he hears it, he turns the switch to the first state, and then the volume of the noise reduces. If he does not hear it, then he turns the switch to the second state, and then the volume of the noise increases. During the examination, the frequency of the noise increases continuously.

Examinations demanding cooperation

- The patient cannot cooperate in the examination (unconscious or infant) or he does not want to (malingerer).
- The responses given to the acoustic stimuli are not evaluated according to the patient's responses but according to the measurement of the brain's action potential (EEG).
- EEG: Electrophysiological measurement device that is intended to record the electrical activity of neurons in real time.

The origin of biopotentials

- Biopotentials are created as a result of the processes taking place on the membrane of the cells.
- Diffusion of neutral molecules, osmotic pressure, migration of ions.
- At room temperature (T = 298 °K) Nerst-equation: $V_1-V_2 = (-58mV)\log(C_1/C_2)$
- $C_1= P_{Na}[Na]_1+P_K[K]_1+P_{Cl}[Cl]_2$
- $C_2= P_{Na}[Na]_2+P_K[K]_2+P_{Cl}[Cl]_1$
- P_x premeability for ion X, $[X]_1$ is the concentration of ion X in chamber 1
- Permeability is a constant that characterizes materials. In the case of solids, gases and liquids, it means the ability to let through.

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Electrodes for the measurement of biopotentials

- The task of the electrodes is to transform ion current into electron current
- Silver-silver chloride electrode, non polarizable, for DC measurements
- Platinum electrode, polarizable
- Stainless steel electrode
- Active electrode, capacitive type, noise tolerance
- Needle electrode, for testing within the body Microelectrodes, for testing within cells thinned glass filled with electrolyte

Chemical sensors

- Metabolic testing
  - The chemical composition of tissues, blood and body fluids
  - The composition of the air we breath in and blow out
- Dalton's law: the pressure of a mixture of gases is equal to the sum of the partial pressures of the gases present in the mixture
- Henry's law: when gas contacts fluid, then the volume of the gas dissolved in the fluid depends on the partial pressure of the gas and its solubility in the given fluid

pO_2 electrode, ion selective electrode

- pO_2 electrode: measures the partial pressure of oxygen in fluids and gases
- Ion selective electrodes: the membrane separating the different fluids is permeable to some ions only
  - A thin glass membrane is permeable only for hydrogen ions (Glass membranes are made of an ion-exchange type of silicate or chalcogenide glass.)
  - The resistance of the electrode is big, 200 – 500 MΩ
- A membrane is a layer of material which serves as a selective barrier between two phases and remains impermeable to specific particles, molecules, or substances when exposed to the action of a driving force.

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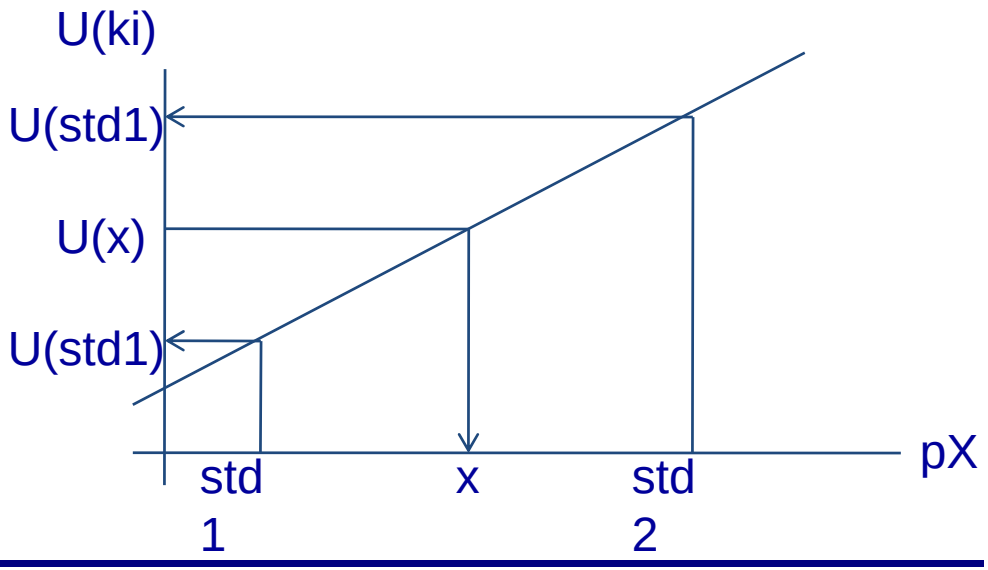
Blood gas analysis

- For the measurement of acid-base balance
- The sample should not contact air
- Primary parameters: pH, pO_2, pCO_2
- High resolution in a narrow range: 0.001 pH
- Frequent calibration



Mechanical sensors

- Measuring displacement, rotation, pressure, force and acceleration
- Resistive transducers, displacement, rotation
- Strain gauge is a device that measures the elongation of a body. Its main type is made of an elastic electric insulating film, which is covered by an electricity conducting layer of the appropriate shape. Is the body is going through a change of shape, the strain gauge undergoes a deformation, too, and the conductor's resistance changes.
- Capacitive transducers
- Inductive transducers, displacement changes the inductance
- Piezoelectric transducers, strain - an electrical signal

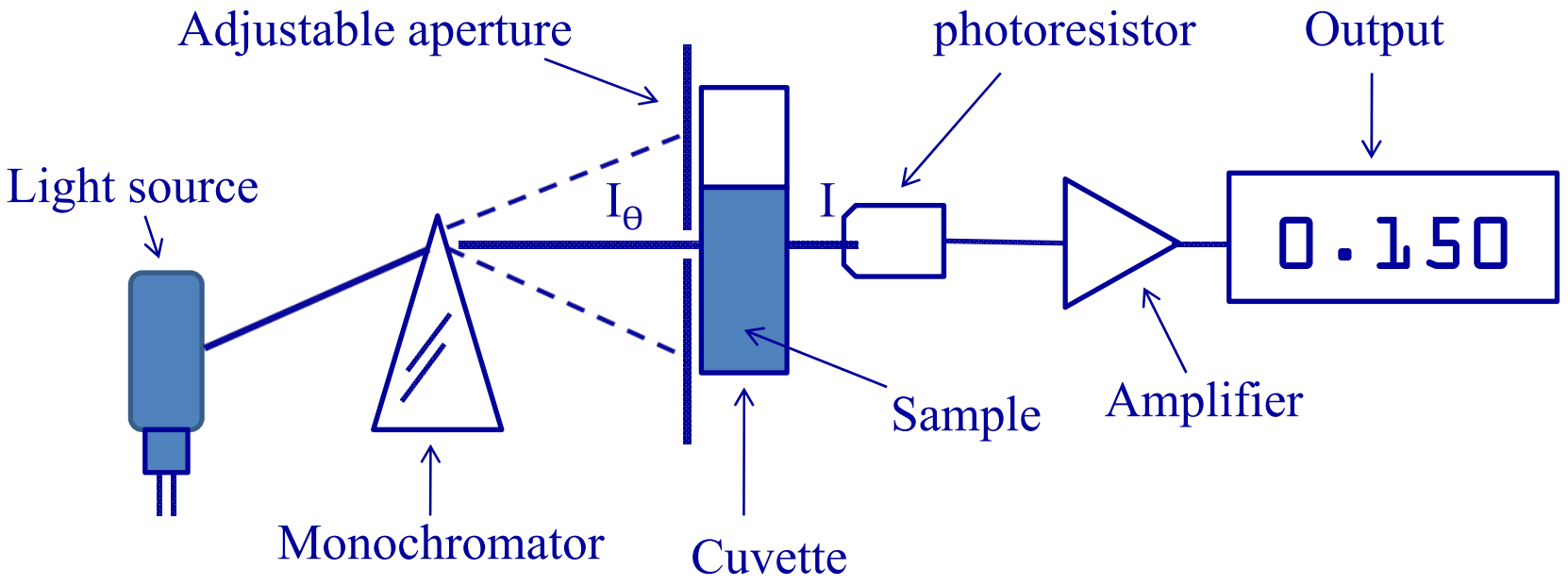
Photoelectric converters

- They measure the intensity of light
- Opacity
  - It completely absorbs light, its energy is converted into heat
  - Passes without a drop in intensity
  - Reflected from the boundary
  - It breaks when it enters a material
  - It is scattered from the boundary of the material
  - It is absorbed and re-emitted (fluorescence)
- Light sensors: photocells, phototransistor, photomultiplier

Light sensors

- Photocells: The photocell is a light-sensitive device based on photoelectric effect, which gives an electric response to the light waves.
- Phototransistor: The functioning of phototransistors is by light, hence these devices usually have two outputs only: an emitter and a collector output. The lightbeam reaches the emitter-base which is working as a photodiode, and photocurrent is starting to flow. The transistor amplifies this photocurrent as base current, so the collector current consists of an amplified photocurrent.
- Photomultiplier: The photomultiplier is made up of a photocathode and an electron multiplier. The output current of the multipliers is proportional to the intensity of the incoming light and electron beams.

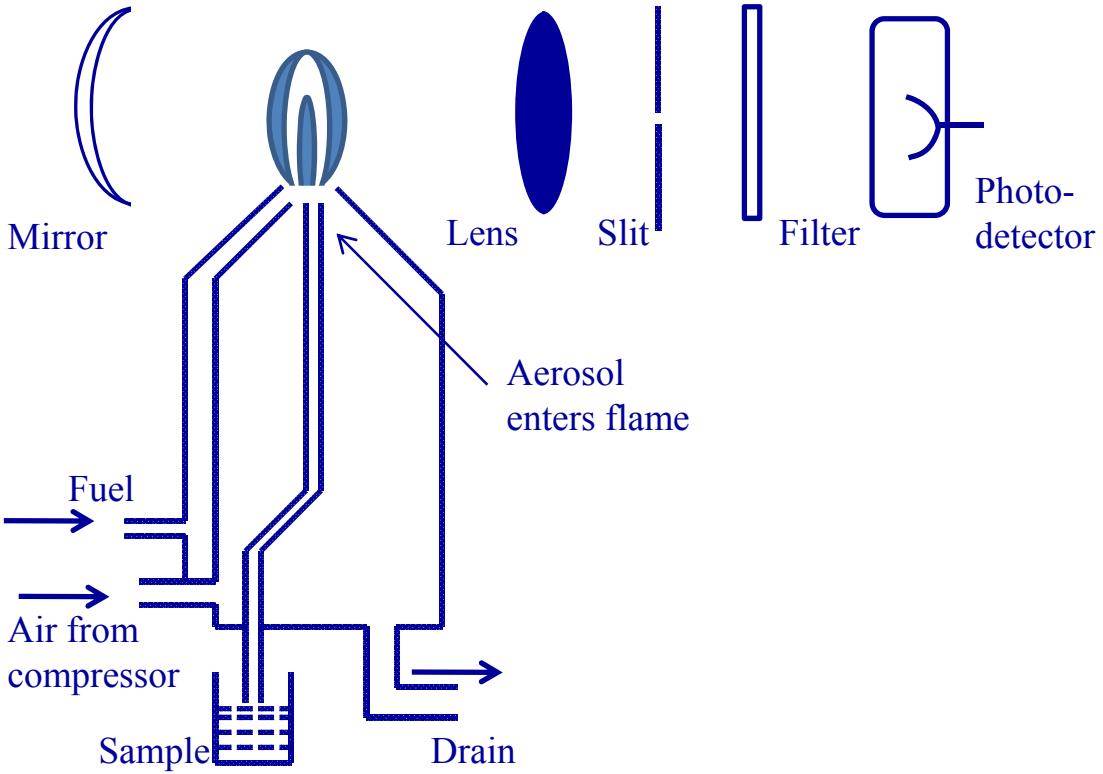
Colorimeter



Colorimeter

- A colorimeter is a device used in colorimetry . In scientific fields the word generally refers to the device that measures the absorbance of particular wavelengths of light by a specific solution . This device is most commonly used to determine the concentration of a known solute in a given solution by the application of the Beer-Lambert law, which states that the concentration of a solute is proportional to the absorbance.
- A cuvette is a laboratory glass tube by which we measure the optical characteristics of solutes.

Flame photometer



Flame photometer

- A photoelectric flame photometer is a device used in inorganic chemical analysis to determine the concentration of certain metal ions, among them sodium, potassium, lithium, and calcium.
- It is a controlled flame test with the intensity of the flame color quantified by photoelectric circuitry. The sample is introduced to the flame at a constant rate. Filters select which colors the photometer detects and exclude the influence of other ions. Before use, the device requires calibration with a series of standard solutions of the ion to be tested.

The characteristics of ultrasound

Mechanical vibration, its frequency is higher than what a human's ear can hear

The resolution depends on the frequency, in medical applications it is between 2 to 12 MHz

Low-ultrasound penetrates the tissue, does not change it, oscillates the material particles

In vacuum, it does not pass, the harder the material, the greater the velocity, it depends on temperature

Vacuum is a three-dimensional volume that basically contains no material, therefore its air pressure is much smaller than standard air pressure.

Ultrasound properties

- On the boundary of two media, reflection and fracture occurs, the reflected beam is called echo
- In medical applications, the air gap between the transmitter (receiver) and the body should be avoided, so gel is used
- Piezoelectric crystals are used in the manufacturing process. The piezoelectric transducers are based on the piezoelectric effect which can be observed at certain non-metallic materials. This effect basically means that these materials, when exposed to mechanical tension (e.g. pressure) are polarized on their surface, creating electric charges.
- The reflected wave function of time is displayed
- Transducers, 2D and 3D ultrasound images

Amplifiers of bio-potentials

- ECG, EEG, EMG, EOG, etc.
- There is no effect of electrode offset voltage, lower cut-off frequency is very low, at ECG it is 0.05 Hz, gains changes in wide range x1... x10^6g, small noise resistance, high input impedance
- High voltage resistance e.g. ECG and defibrillator
- The amplifier must be protected, but also the patient
- Disorders such as ground loop, magnetic or capacitive coupling

Amplifiers of bio-potentials

- Electroencephalography (EEG) is an electrophysiological measurement device that is intended to record the electrical activity of neurons in real time.
- Electromyography (EMG) is a technique for evaluating and recording the electrical activity produced by skeletal muscles.
- Electrooculography (EOG/E.O.G.) is a technique for measuring the resting potential of the retina. The resulting signal is called the electrooculogram. The main applications are in ophthalmological diagnosis and in recording eye movements.

Amplifiers of bio-potentials

- Patient is not grounded
- Negative feedback for the common cutaneous voltage, "driven right leg"
- Twisted pair, shielded: The wires are twisted together in pairs, thus reducing the distorting effects of electromagnetic and radio frequency interference. Crosstalk between unshielded pairs is reduced by the different twisting of the pairs.
- Isolated amplifiers, battery powered, isolation by transformer or optical transmission
- Multichannel amplifiers, ECG up to 200 channels of the same structure

Biological signal processing

- Separation of useful signals and unwanted signals
- Usually time-domain (averaging, correction computation, pattern matching) and frequency domain (Fourier analysis, filtering) techniques, wavelet analysis, etc.
- Data compression is an area of computer science aimed at processing data in a way that they acquire less space, or they can be transmitted as quickly as possible.
- Regularity qualification and test of a coincidence in sequences: the expected value difference may indicate regularity.

Security Systems

- 1-10 mA detection limit
- 10-100 mA detention current, the stimulation of the nerve and the muscle stops to let go
- 50- mA respiratory paralysis, and pain in muscles
- 100- mA Ventricular fibrillation (The phenomenon of fibrillation is caused by the different contraction rhythm of the heart muscle fibers, when instead of contractions, the heart is only shaking.), self-sustaining state, requires the use of defibrillators
- 1- A complete heart muscle contraction
- 1- A burning, muscle tear

Macroshock and microshock

- Cutaneous chain is: macroshock (Any electrical current that passes through the skin and into the body that is larger than 10mA is considered a macroshock.)
- Microshock : Is a risk in patients with intracardiac electrical conductors, such as external pacemaker electrodes. A current as low as 10uA directly through the heart, may send a patient directly into ventricular fibrillation.
- Physiological effect depends on the weight, connection points of location, size of the current, mood
- Skin resistance : 10 kOhm – 1 MOhm
- Resistance of the internal organs: 100 – 500 Ohm
- In case of microshock c x 10μA causes ventricular fibrillation

Problems – solutions

- P: short circuit : A electrical phenomenon between two or more conductors different voltages, when they get into a conducting connection through a very small resistance (impedance).
- P: leakage current due to capacitive coupling, P: Bad grounding
- Small resistance protective grounding
- GFCI ground-fault circuit interrupter: Is an electrical wiring device that disconnects a circuit whenever it detects that the electric current is not balanced between the energized conductor and the return neutral conductor.
- GFCI can not be in an intensive care room, respiration machine
- Galvanic isolation, battery-powered, double insulation

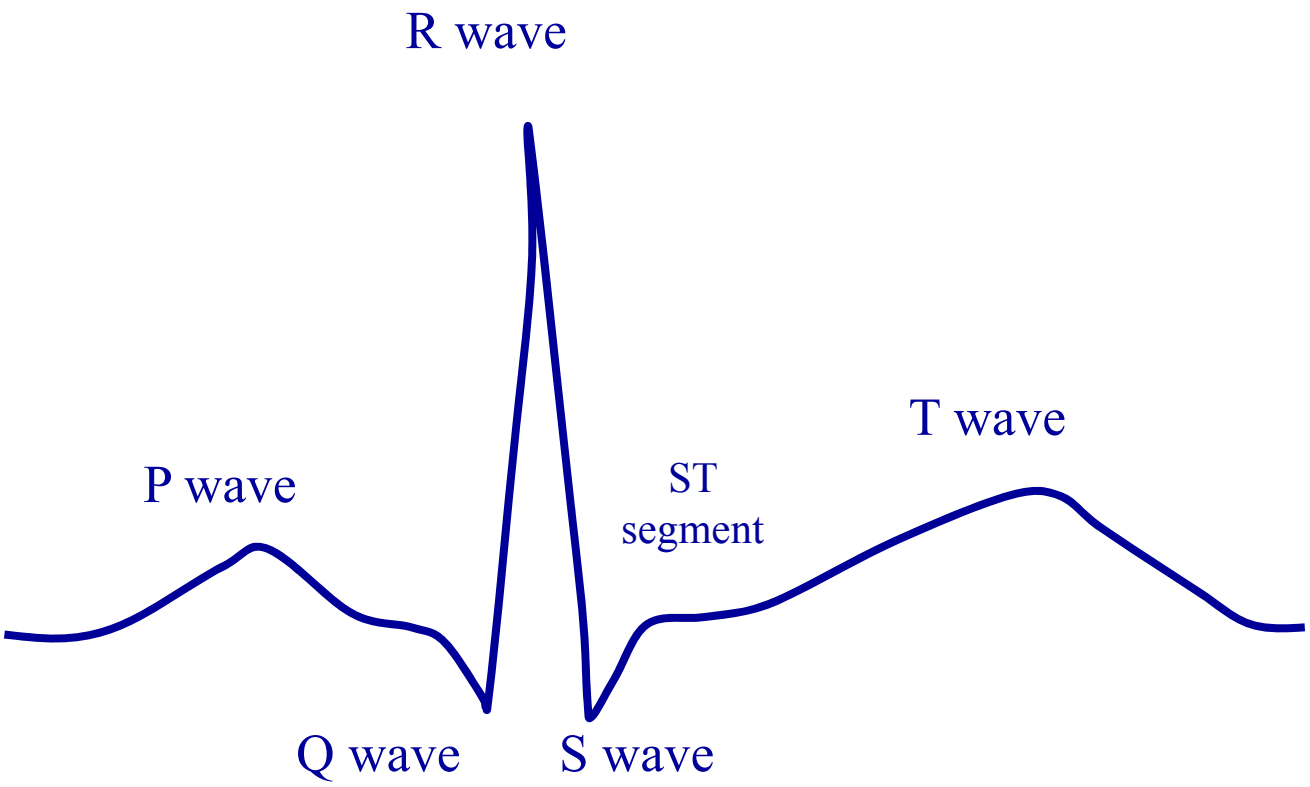
ECG signal

- 1 million cardiac muscle cells
- Depolarizing the cell proliferation state
- The sinus node determines the frequency of the right atrium (Sinus node is the regulatory centre controlling the contractions of the muscles of the heart in the wall of the right atrium.)
- Blood from atria to the ventricles, then to arteries
- Heart activity is measured on body surface
- Appropriate model is needed, the most common characterization by dipole (Dipole: A separation of positive and negative charges.)

Eindhoven's assumptions

1. The heart's electrical activity can be described by a dipole in every moment
2. The limb leads (right hand, left hand, left foot) peaks correspond to an equilateral triangle
3. Between the heart and limb leads homogeneous conductivity of tissues are located

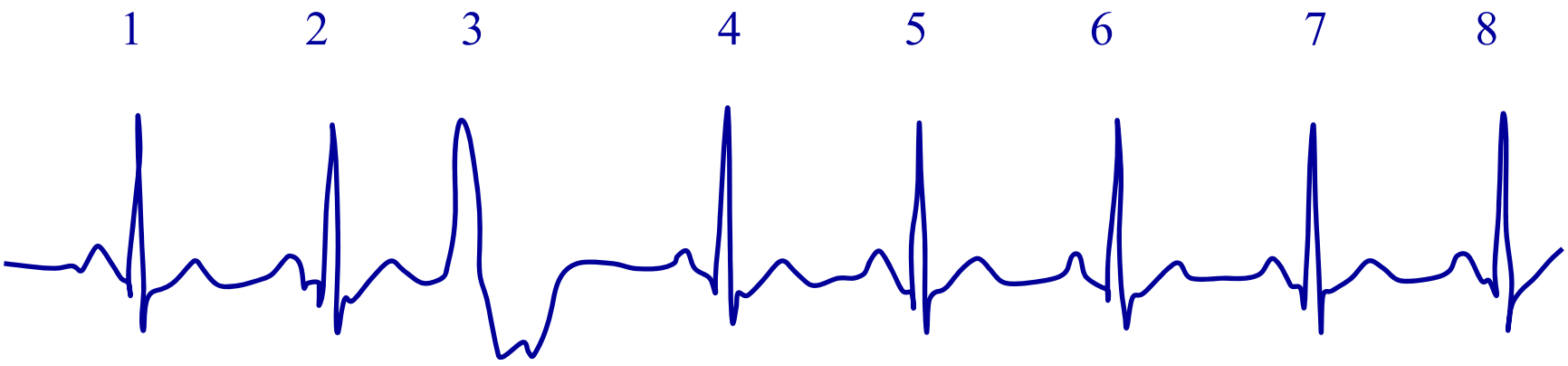
ECG function



ECG parameters

- Instantaneous heart rate, RR distance
- Heart rate averaged over several cycles
- Time data counted within a cycle: PQ, QT, ST distances
- Cycle shape analysis:
  - climb of ST segment,
  - Shape and size of R peak
  - area under the P, R, T wave (Generally, the algebraic sum of the areas which the curve on the x-axis encloses.)

Pathological ECG signals



ECG instruments

- Diagnostic ECG recording device when the patient lies
- ECG for stress test
- 24-hour Holter ECG recording, this system records all heartbeats for 24 hours, and a computer system evaluates it. Thus, at any time during the day, an arrhythmia can be detected.
- ECG used in ER
- ECG used in defibrillators
- ECG testing athletes with transmitter
- Fetal ECG heart testing

ECG stress test

- Before the test, ECG electrodes are connected to the body, and a blood pressure cuff is placed on the arm. The patient is asked to perform treadmill or exercise bike move. The ECG machine records the electrical signals from the heart on a paper tape. Before the test, a target heart rate per minute was set. The load, i.e. the difficulty of turning the pedal or the speed of the runner may be increased gradually. The test is over, if the test person has reached the prescribed heart rate, or if during the test, chest pain (angina) occurs, if blood pressure is too high or ECG abnormalities occur.

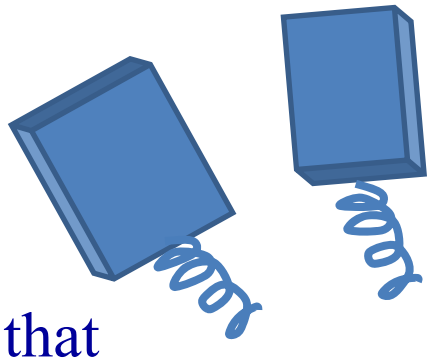
Heart rate control

- It issues a pulse if it does not detect a pulse given by the sinus node in a given time
- It is implanted under the skin
- The electrodes in the cardiac chambers are connected with flexible wires.
- Power is important
- They are programmable
- It can have many kind of sensors: blood temperature, period measurement, area under the R-wave, pH value, changes in blood pressure, volume of heart chamber

Heart rate control

- Generator: a small computer and an incorporated battery of many years of life.
- Electrodes: special-coated wires connecting the heart muscles and the generator.
- The pacemaker - which is the size of a pocket watch - is usually placed under the skin layers in the recess of the shoulder, the clavicle and the large pectoral muscle. The electrodes are led through the blood vessels and fixed in the heart chambers, or in the case of open surgery, they are fixed to the outer surface of the heart. The generator has a small pouch under the skin.
  The device can also have programs that adapt to the functioning of the heart, or to physical activity. The more advanced devices allow for full and active life, even a regular sport.

Defibrillators



- Restoring orderly contraction and relaxation
- Releasing a single, high energy, short pulse, so that the cells of the heart get the same electric status
- In the case of an atrial fibrillation, an AC defibrillator might cause a ventrical fibrillation … so DC defibrillators are used
- It can be re-used in 10 ms
- Current can be maximum 90 A, appropriate electrode

Measuring blood pressure

Direct method: catheter (outside the vein), pressure sensor (inside the vein)

Indirect method: cuff on the upper arm

- The pressure within the cuff is slowly reduced. Basic principle: when the arterial pressure is bigger than the cuff pressure, the blood is flowing in the arteries, when the pressure in the cuff is bigger, blod is not flowing in the arteries.

In the case of a quick deflation, methodological errors may occur

Korotkov's sounds: the pressure of the artery is judt bigger than the pressure of the cuff, Systole, diastole sounds.

Breath test

FRC = Functional Residual Capacity

TV = Tidal Volume

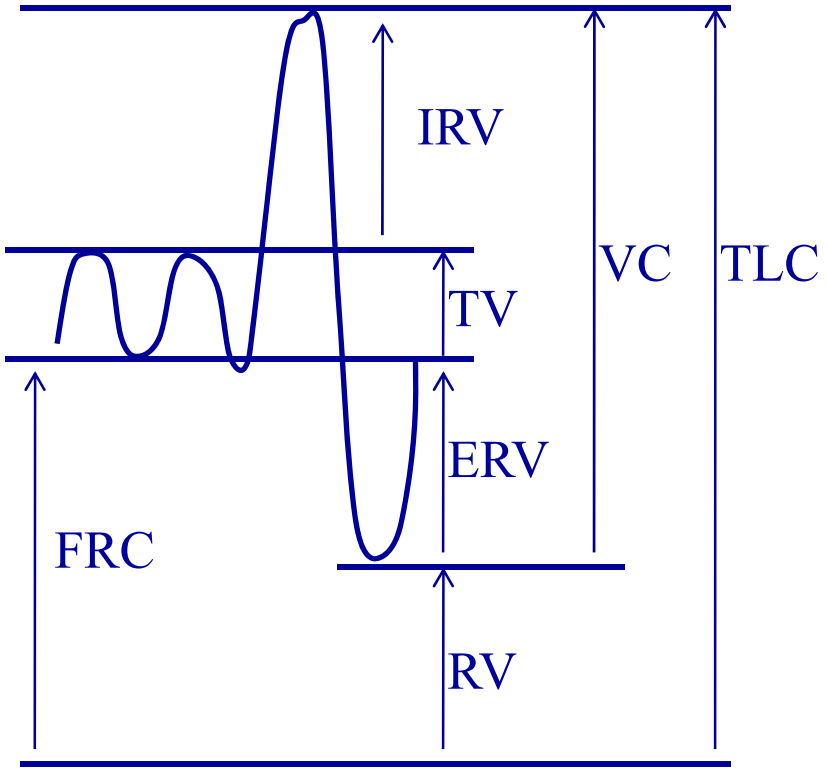
VC = Vital Capacity

RV = Residual Volume

TLC = Total Lung Capacity

ERV = Expiratory Reserve Volume

IRV = Inspiratory Reserve Volume



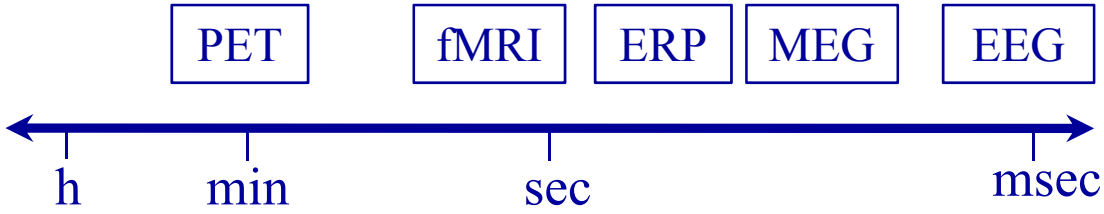
Breath test

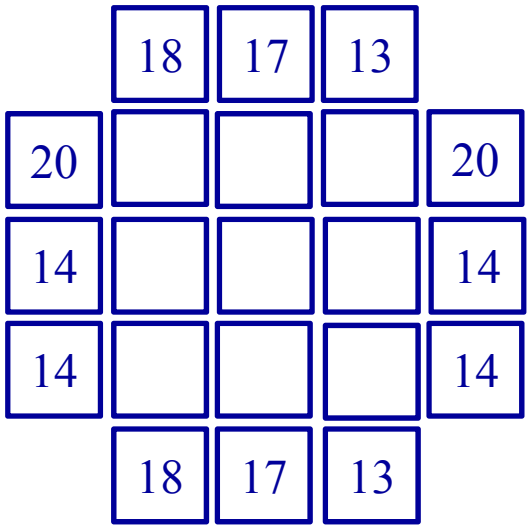
- Tidal volume:The volume of air inhaled and exhaled at rest. Normal value is approx. 500 ml.
- Vital capacity: The sum of the tidal volume and the inspiratory and expiratory reserve. Its normal value is 4800 ml.
- Residual volume: After the maximum expiration, approx. 1300 ml air remains in the lungs.
- Total lung capacity: The sum of the vital capacity and the value of the residual air. In the sace of an adult male it is approx. 6000 ml.
- Expiratory Reserve Volume: After normal expiration, the further maximum expiration is approx. 1000 ml.
- Inspiratory Reserve Volume: From the maximum volume of air flowing into the lungs by inhalation (ca. 3500 ml), we subtract the value of the tidal volume (ca. 500 ml) = ca. 3000 ml.

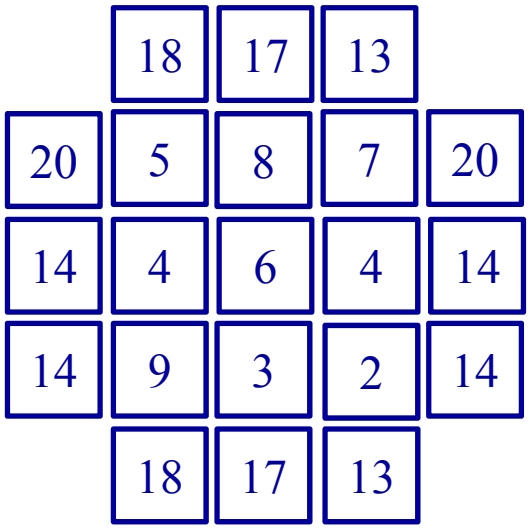
Functional imaging techniques

- Function - the brain structure
- Biological imaging methods
- PET positron emission tomography
- fMRI functional magnetic resonance imaging
- EEG, MEG magneto-encephalography, electro-encephalography BEAM (brain electric activity mapping)
- Potential ERP related event - related potentials method
- Pléh at all: Cognitive Neuroscience

Basics of tomography







Functional imaging techniques

- An important characteristic of PET and other conventional imaging techniques (eg fMRI, SPECT) is that they do not feature anatomical relations, but the different functional characteristics of organs and tissues (eg, blood flow, metabolism) in a given moment. Since the onset of a disease first damages the functional characteristics of organs and tissues, and usually anatomical changes accompanythese secondarily, it is important that the functional imaging techniques indicate the onset of a disease much earlier, even before anatomical changes.

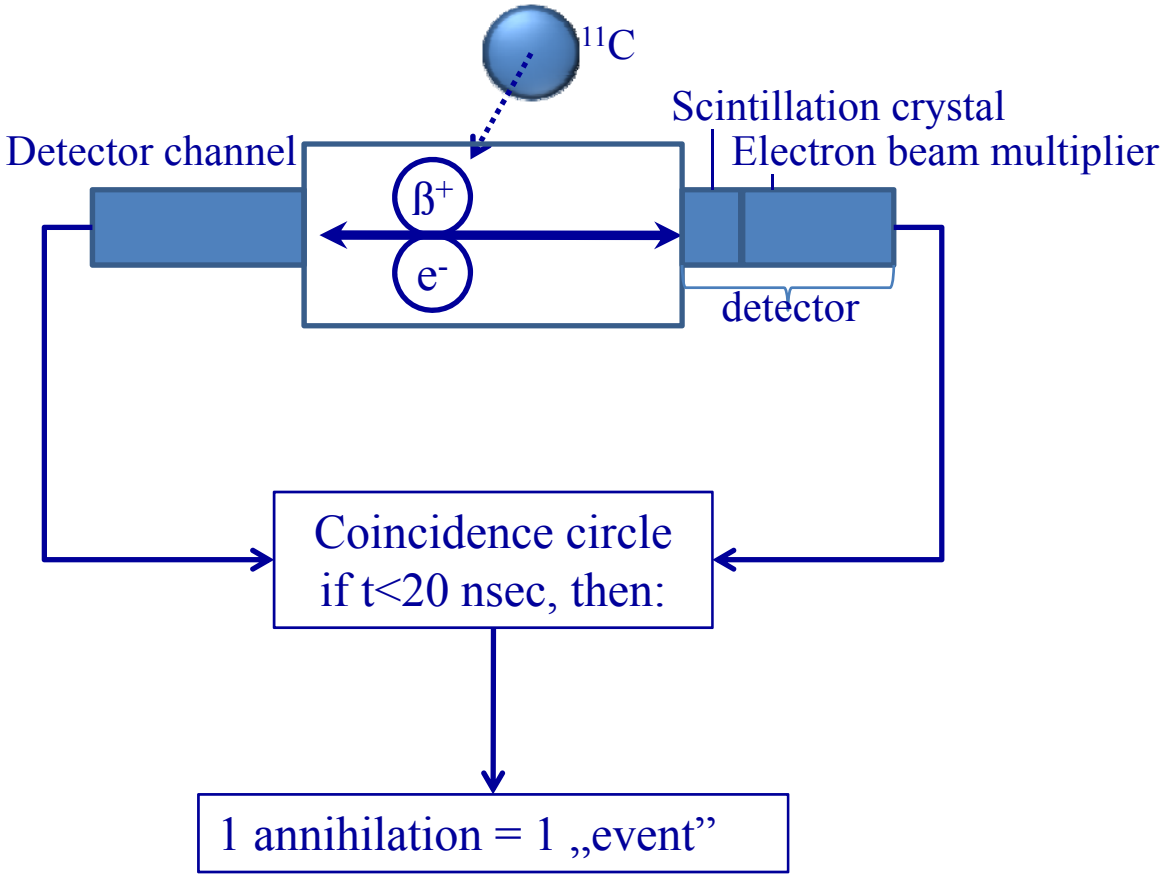
Functional imaging techniques

- The operation of positron emission tomography is based on that the molecules marked by positron radiating isotopes help the representation of the biochemical processes of the body.
- The functional MRI or functional magnetic resonance imaging (fMRI) is a specialized type of MRI measuring the hemodynamic response in connection with neural activity in the brain or spinal bundle of humans and animals.
- MEG is an imaging process measuring and registering the magnetic field caused by the electric activity of the brain, with the help of sensitive detectors like SQUIDs (superconducting quantum interference).

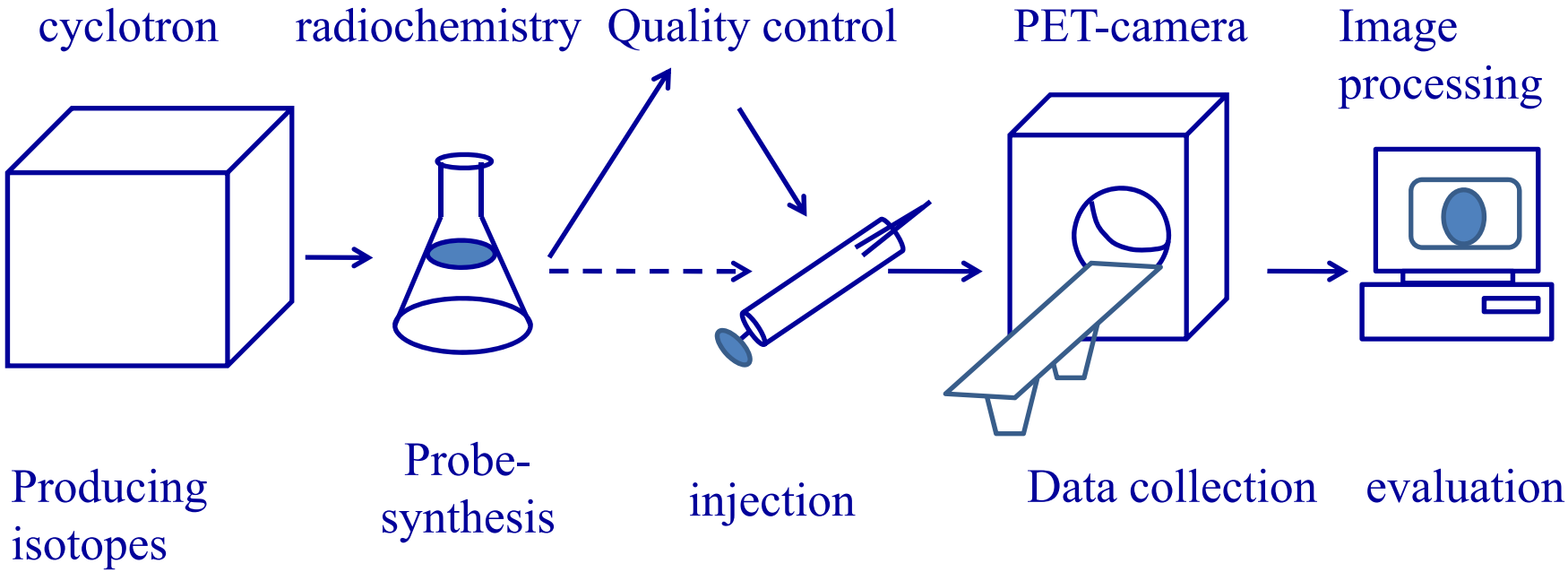
Comparison of tomographic principles

	MRI	CT	SPECT	PET
Base	magnetic resonance of nuclei	X-ray transmission	photon-emission	positron-emission, coincidence detection
Used probe	gadolinium	iodine contrast agent	photon emitting radionuclides	positron emitting radionuclides
Most commonly used isotopes (PET, SPECT) and investigated atoms (MRI)	^{1}H, ^{23}Na, ^{31}P	no	^{123}I, ^{131}I, ^{99}Tc, ^{133}Xe	^{11}C, ^{13}N, ^{15}O, ^{18}F
Especially considering	structure	structure	function	function
Best spatial resolution (mm)	< 1	1	4--5	2,8
Typical data collection time (minute)	20	2	15	20
Average exposure to a biological test (mSv)	no	2--8	6--10	2--10

Coincidence detection in PET

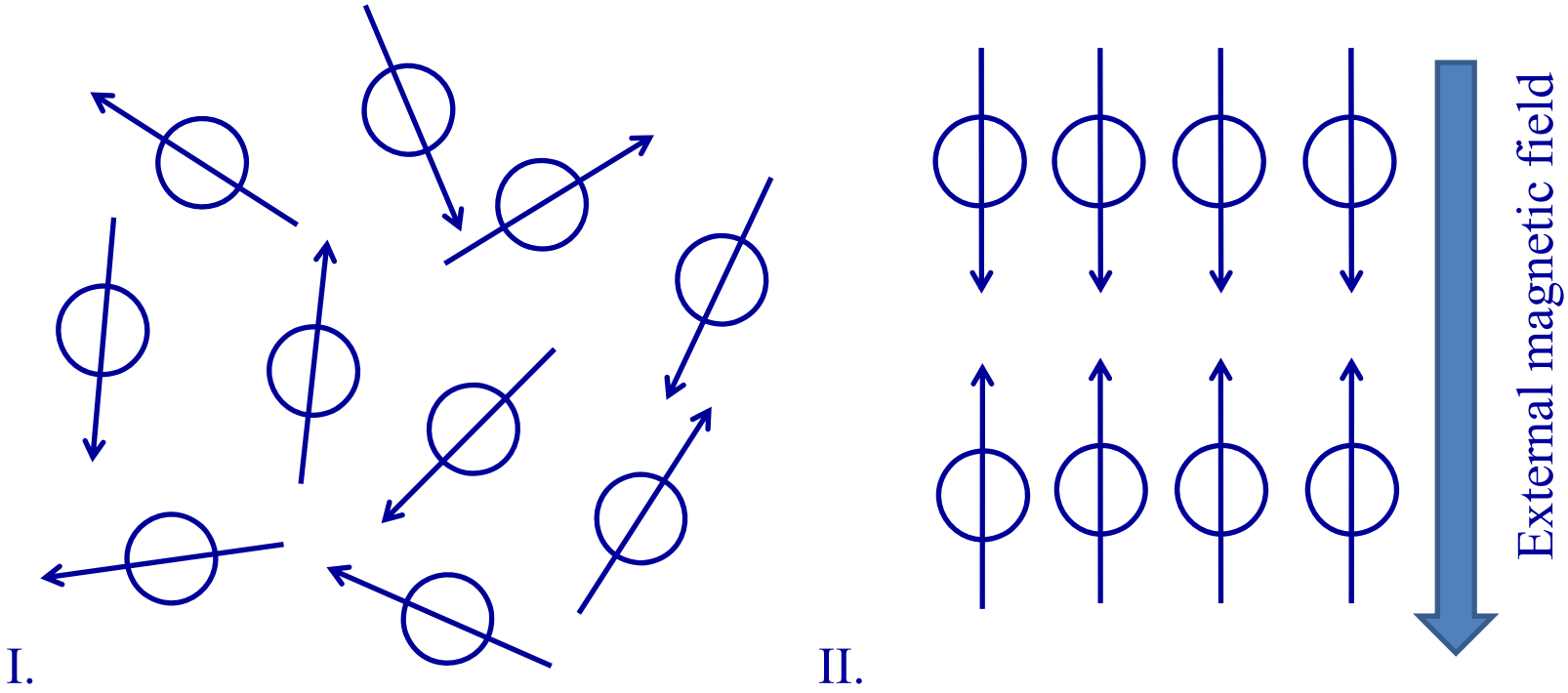


PET system

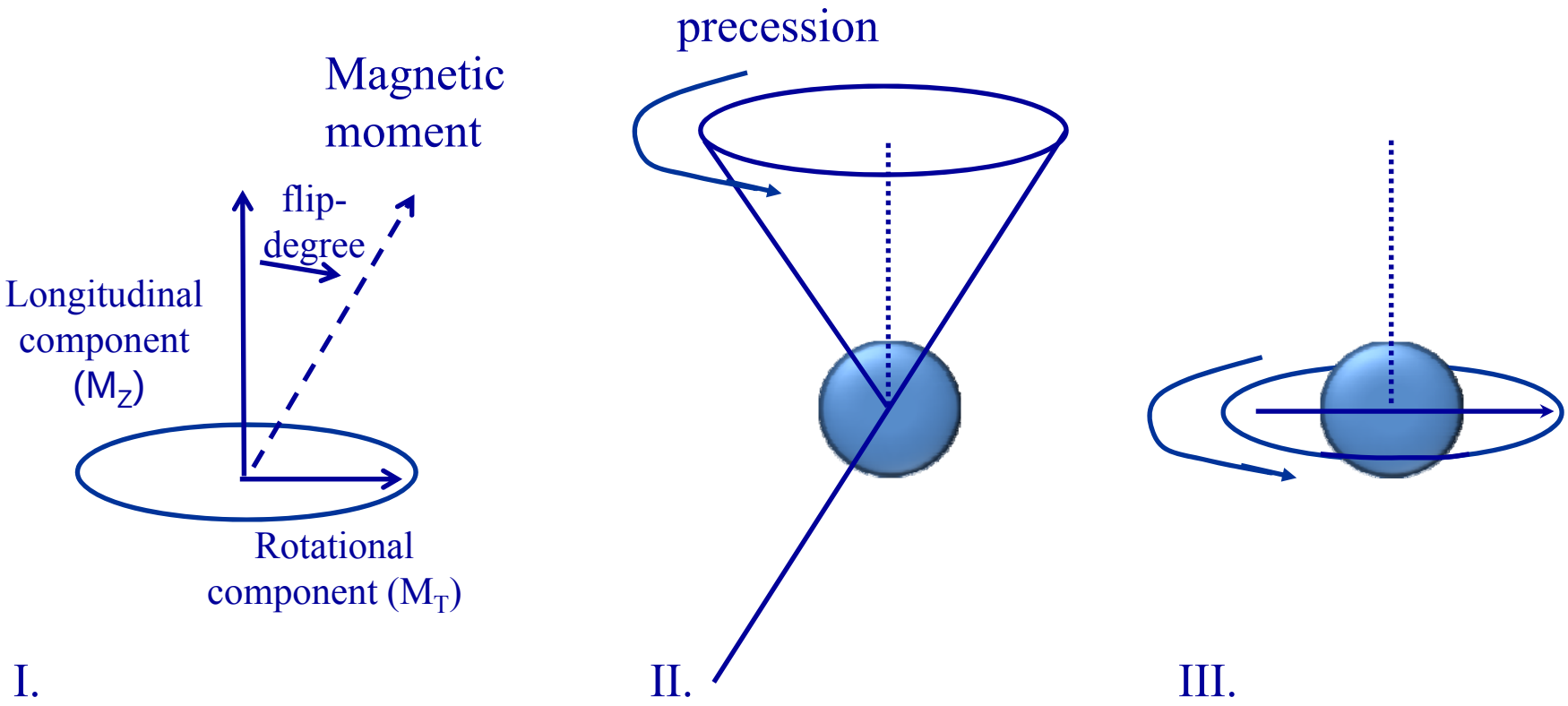

cyclotron
radiochemistry
Quality control
PET-camera
Image processing
Producing isotopes
Probe-synthesis
injection
Data collection
evaluation

- Blood flow and blood volume
- Tissue pH
- Metabolism and transport
- Oxygen
- Glucose, glucose analogs and metabolites
- Amino acids (for example metiolin, tyrosine, alanine, leucine)
- Free fatty acids
- Fluorine
- Molecular diffusion
- Membrane permeability
- Neurotransmitter and receptor systems
  - Dopaminergic, cholinergic
  - benzodiazepine-GABA
  - Opioid
  - Adrenergic
  - serotonin, muscarinic
- Enzyme activity and enzyme concentration in situ hybridization
- Secondmessenger systems
- Pharmacokinetic and pharmacodynamic parameters

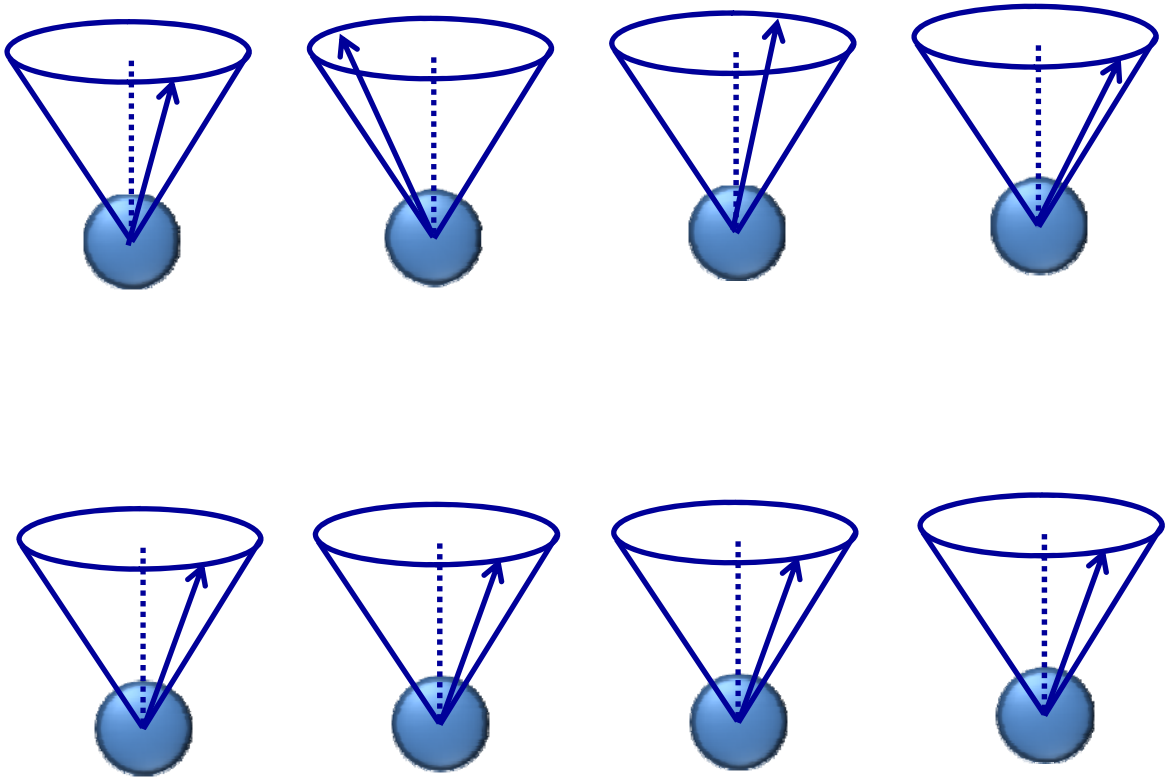
fMRI – magnetic moment of the hydrogen proton



Magnetic signal



Magnetic resonance



The advantages of fMRI

- It can make recordings of the activities of the brain in humans and animals without the risk of radioactivity, which is a risk in the case of other processes like CT.
- It can make recordings of a 3–6 mm2 area, which is very good as compared to the spatial resolution of EEG, but this has a relatively poor temporal resolution as compared once more to EEG technology. EEG measures the electrical/neural activities, while fMRI measures the activity of the blood, which in any case has a longer response. The MRI equipment (which can be used for fMRI experiments as well) has a high temporal resolution, if it measures a different phenomenon.

fMRI examination

- The participants involved in the fMRI studies are always asked to lie as still as they can and avoid even minor movements, since these might interfere with the measurement. Although it is possible to make certain corrections on the data after the experiment, and the minor movements of the head can be treated, but bigger movements might completely ruin the examination. The movements bigger than 3mm usually result in completely unusable data. Motion may occur in the case of anyone, but it is the most remarkable in the case of individuals, who are physically or emotionally unprepared to MRI examinations (e.g. in the case of Alzheimer's disease or schizophrenia, or young children).

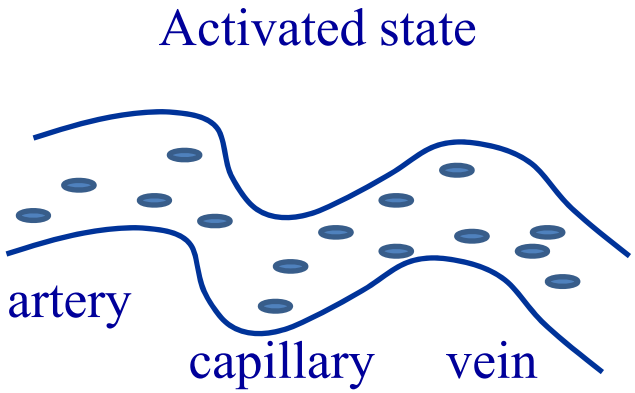
fMRI examination

- An fMRI examination usually takes about 15 minutes to 2 hours. Depending on the objectives of the examination, the participants either watch a film or listen to sounds. Sometimes they should smell different things, or they should perform certain cognitive tasks like counting backwards, memorizing or imagining things, pushing buttons, etc. The investigations require the detailed instruction and exhaustive presentation of the experimental plan for each subject. After this, the test people should concent to the implementation of the experiment in writing, if they agree with the conditions.

fMRI examination

- Security is a very important factor in any kind of MRI experiment. Potential subjects must make sure that they can enter the MRI unit safely. This security step is due to the nature of the MRI scanner, as it is surrounded by a very strong magnetic field (at least 1.5 Tesla, but sometimes it is even stronger than that). Subjects must be checked with full attention: they must not wear any objects made of metal nor any magnetic objects like watches, glasses, hair pins, pacemaker, or any kind of screws or metal implants in their bones. Before the examination, it is forbidden to enter the scanner unit!

Blood Oxygenation Level Dependent



- Blood flow: basic level
- Cell metabolism: basic level
- Oxygen metabolism: basic level
- Oxygen extraction: basic level
- Oxyhemoglobin: basic level
- Deoxyhemoglobin: basic level
- Oxi-Hb/deoxi-Hb: basic level
- MR signal: basic level