

UiO : Department of Physics
University of Oslo

FYS 4250

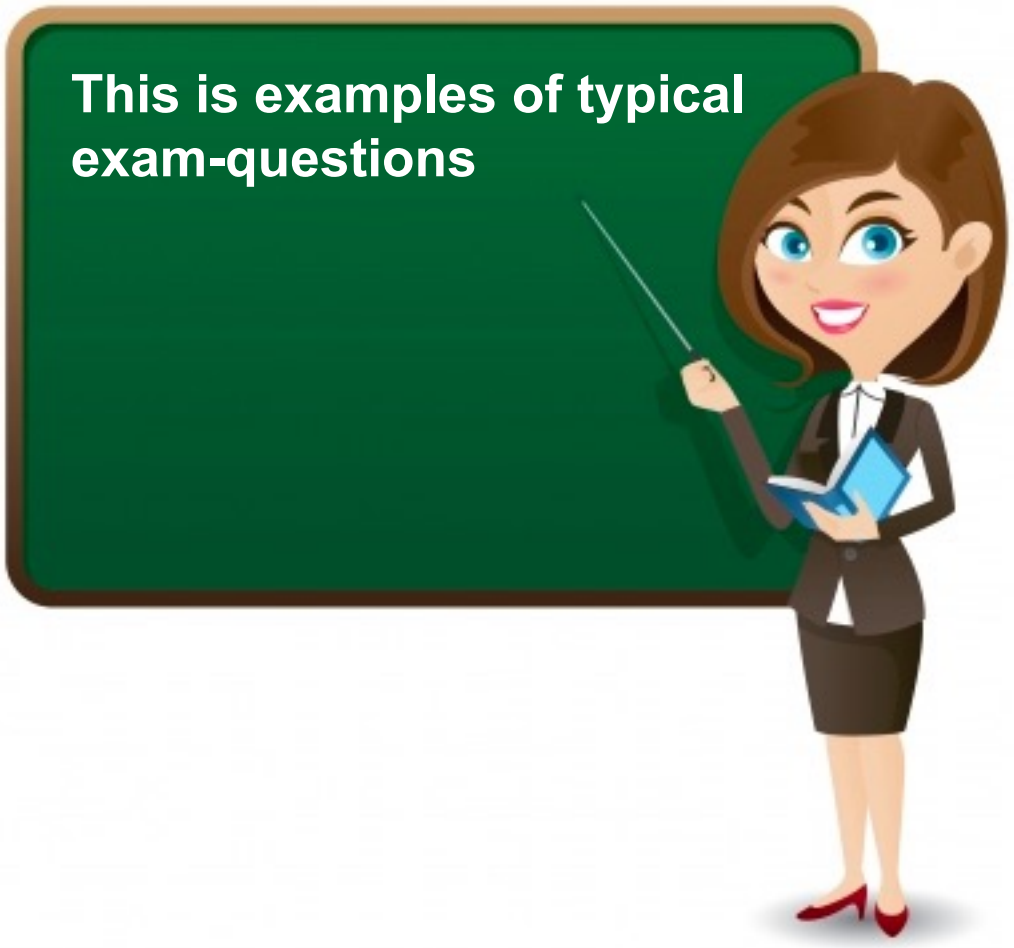
Repetition part 9-15



What is a typical question?

Examples:

1. What are the main physical principles that we utilize in order to generate an MR-image?
2. What is the difference between T1 and T2, and what is the consequence in practical life?
3. Which imaging method is best for giving a quick and precise diagnosis of the function of an aorta valve?
4. Why is still a PET-CT the preferred method for nuclear cancer-imaging?
5. Why is proton-therapy considered to be the ultimate non-invasive cancer removing technique, and why is ultrasound-therapy still number two?



This means that this slide is especially important



http://kidmechanix.com/wp-content/uploads/2017/06/ABAprinciplesforteachers.jpg



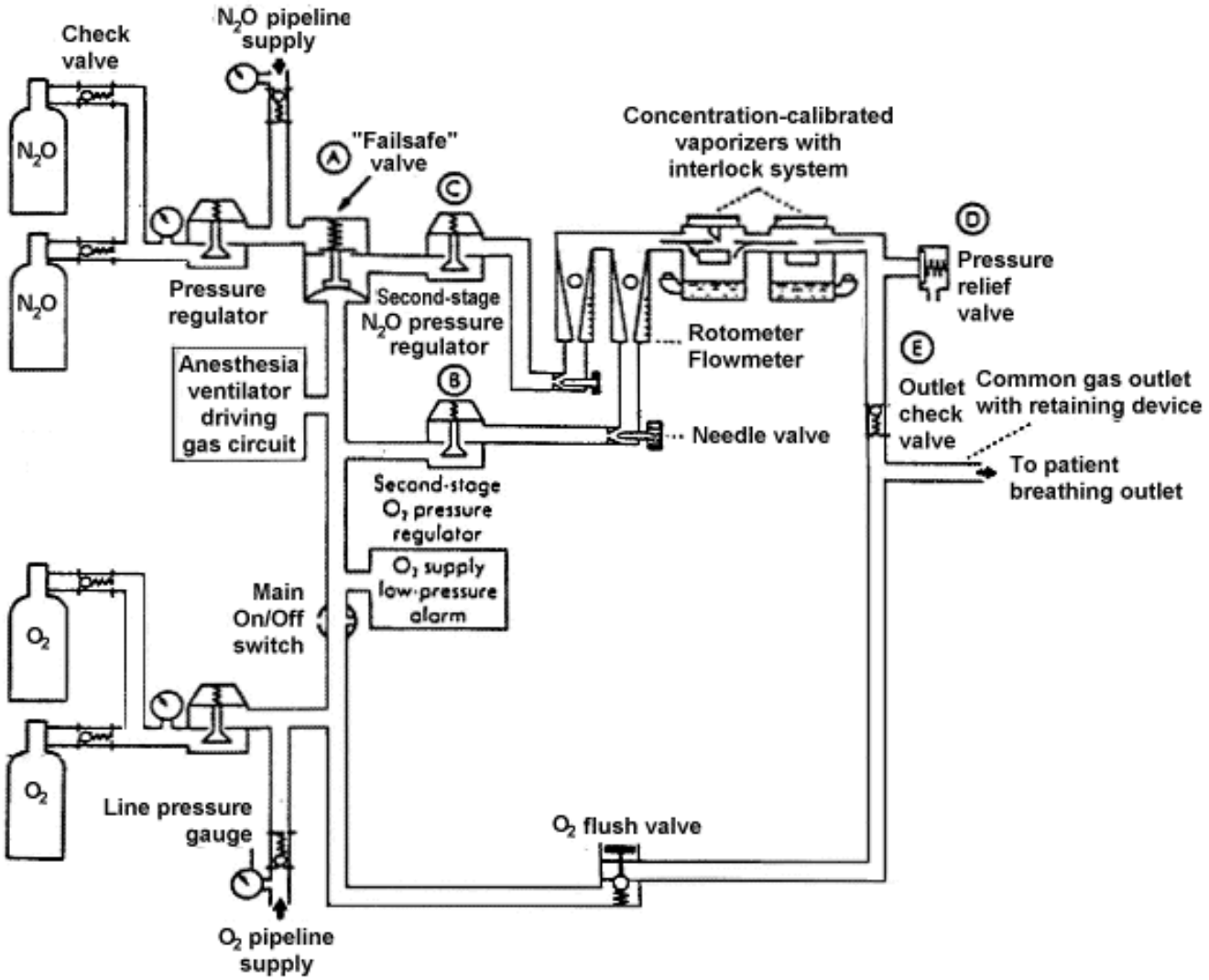
UiO : Department of Physics
University of Oslo

FYS 4250

Lecture 9



Anesthesia machine, overview



The Anesthesia Workstation

Main functions:

a. Provide anesthetic drugs in correct concentration
b. Take care of the waste
c. Ventilate the patient
d. Monitor the vital signs during anesthesia



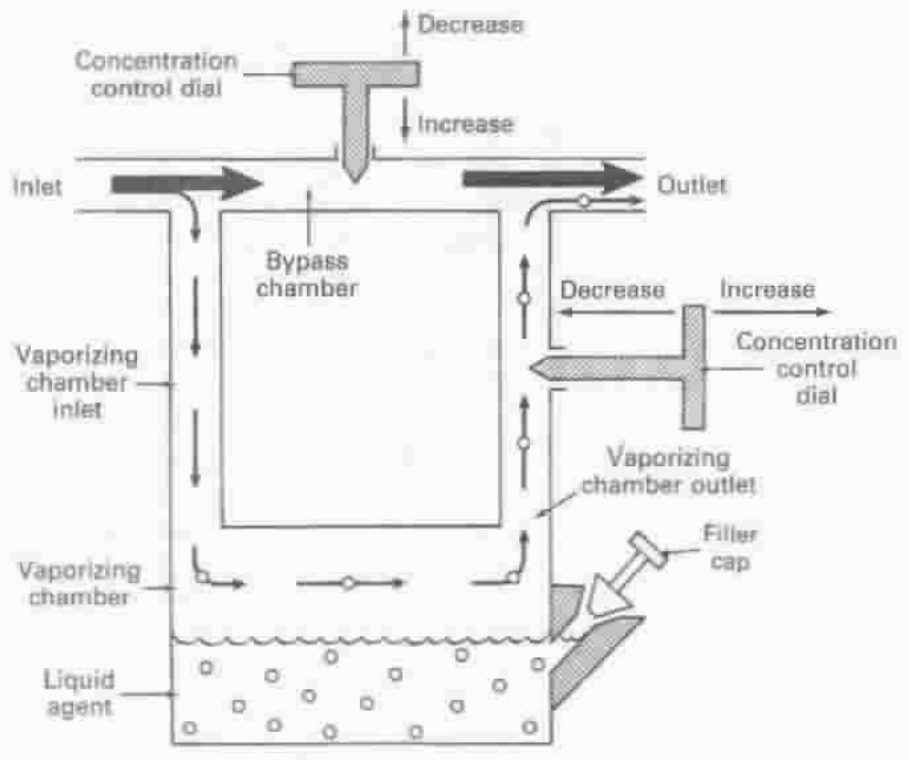
Main concerns:

1. Wrong gas concentrations
2. High pressure
3. Rebreathing
4. Leakages

www.medicalexpo.com

The vaporizer

A vaporizer will change the liquid anesthetic agent into a vapor and insert a certain amount of this vapor into the fresh gas flow

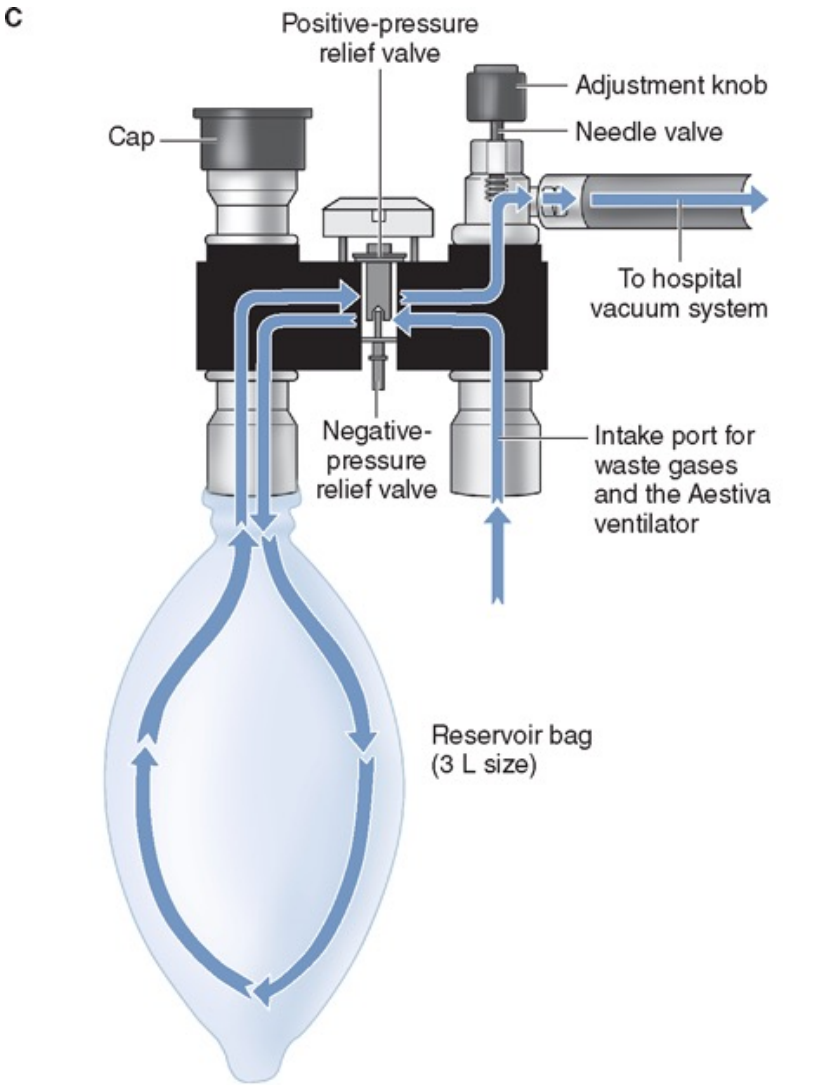


http://www.vajira.ac.th

Main source of error?

b. Scavenging system

Scavenging system



Source: Butterworth JF, Mackey DC, Wasnick JD: *Morgan & Mikhail's Clinical Anesthesiology*, 5th Edition: www.accessmedicine.com

Copyright © The McGraw-Hill Companies, Inc. All rights reserved.

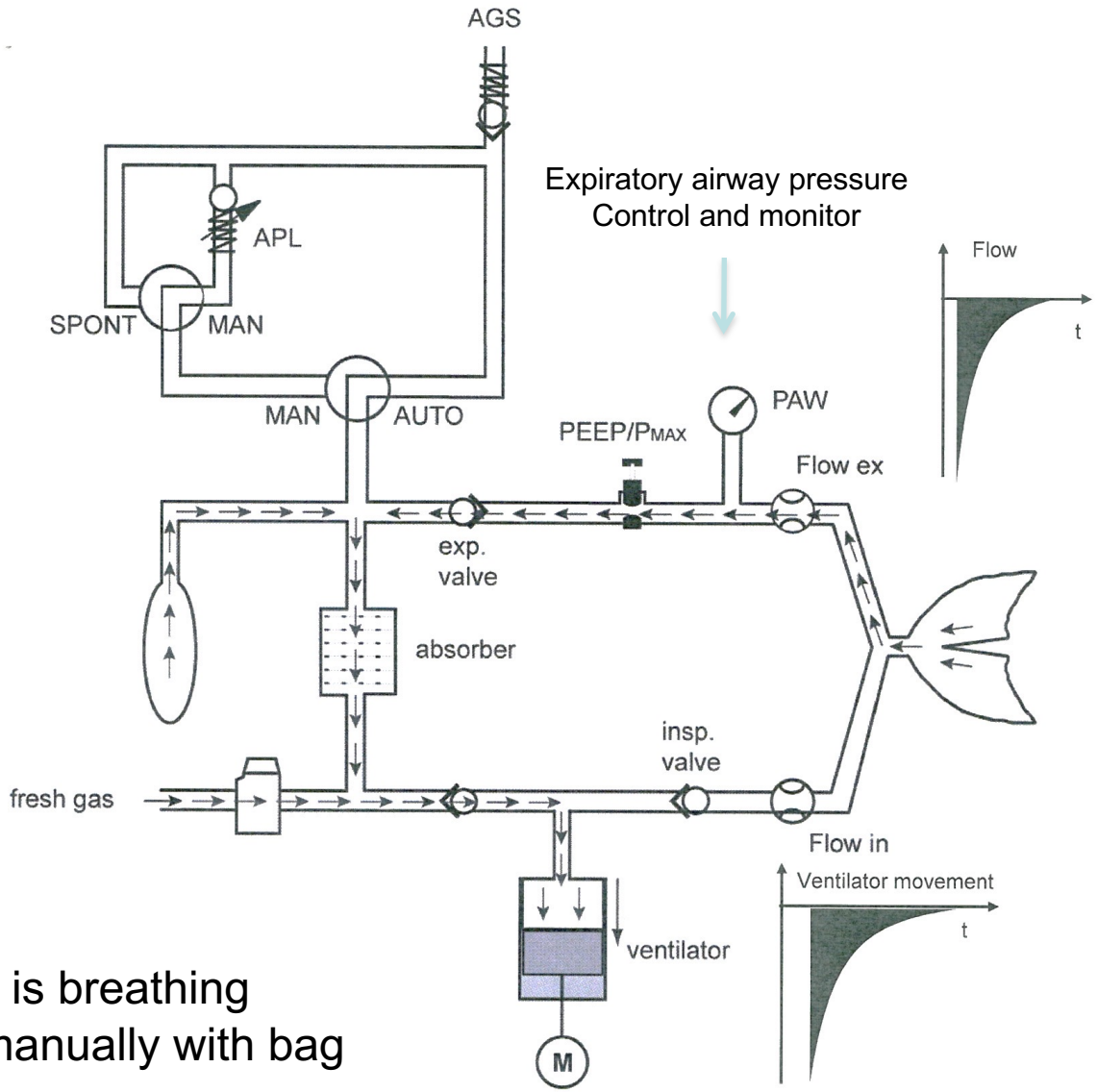
c. Ventilate the patient





Adjustable pressure limiting valve provide control of the pressure in the breathing circle

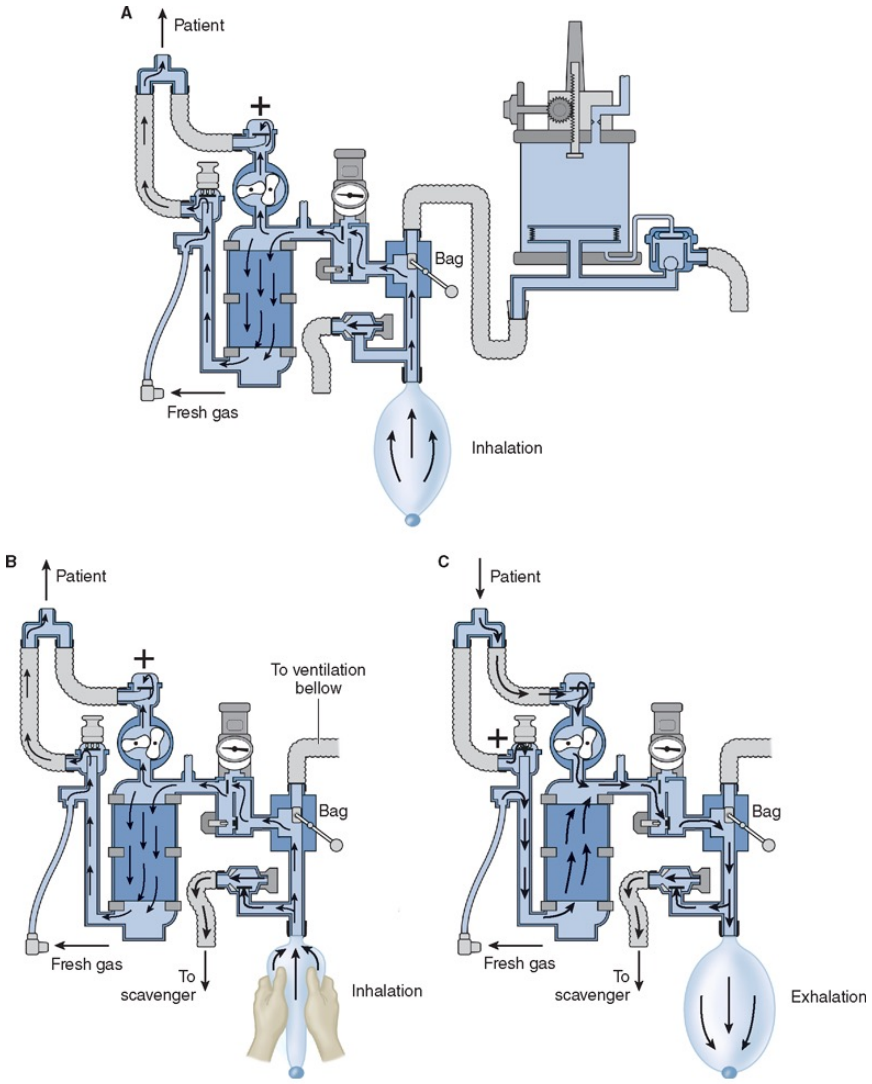
The patient circle



Three modi:
Spontanous – Patient is breathing
Manual - Ventilating manually with bag
Auto - Ventilator

Inhalation/exhalation with bag (Manual ventilation)





Source: Butterworth JF, Mackey DC, Wasnick JD: *Morgan & Mikhail's Clinical Anesthesiology*, 5th Edition: www.accessmedicine.com

Copyright © The McGraw-Hill Companies, Inc. All rights reserved.

Exhalation
Air from the patient together with fresh gas is filling the bag, the excess is evacuated through the APL-valve

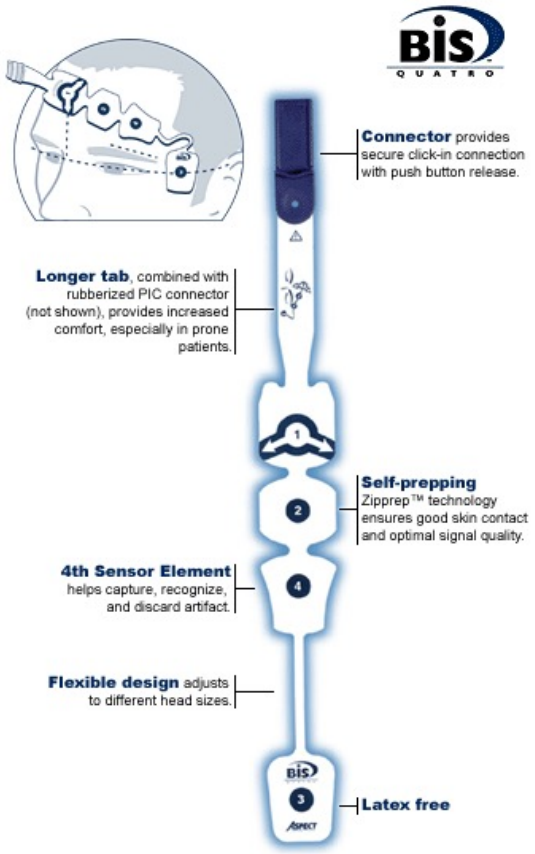
Inhalation
The bag is squeezed and the air is pushed through the calc absorber (soda lime) into the patient. The exhalation valve makes sure that there is no backflow of air (Rebreathing)

d. Monitor vital signs



Sleep depth: Bispectral index score (BIS)





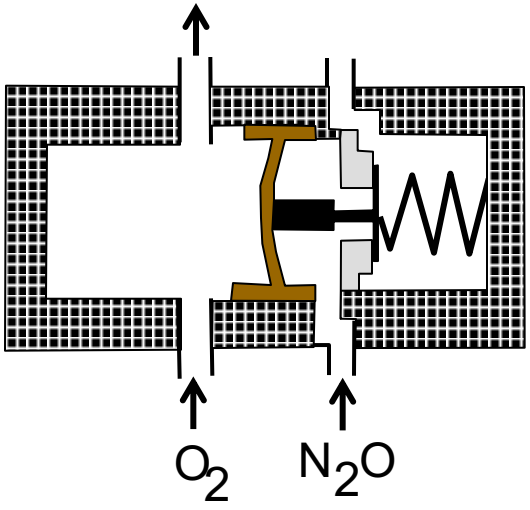
http://bcrt.ca/wp-content/uploads/2009/07/bis.jpg

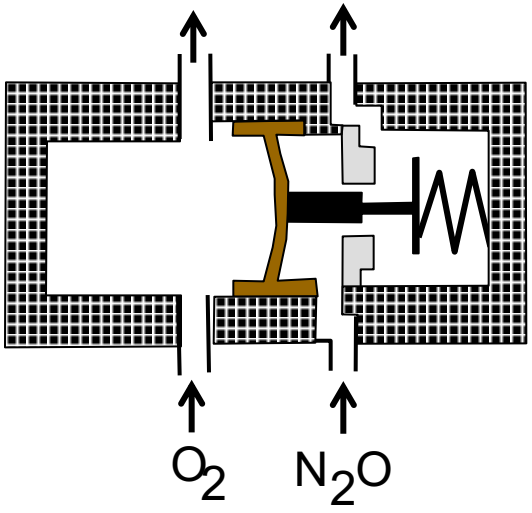
http://www.firesa.co.za/medical/1f65e210.gif



Wrong gas concentrations

Accident: Leakage from O_2 to N_2O





2-room slave regulator



Wrong gas concentrations

Accident: No O2 flow

Berge Grimnes: Gassteknisk medisinsk utstyr Del 2

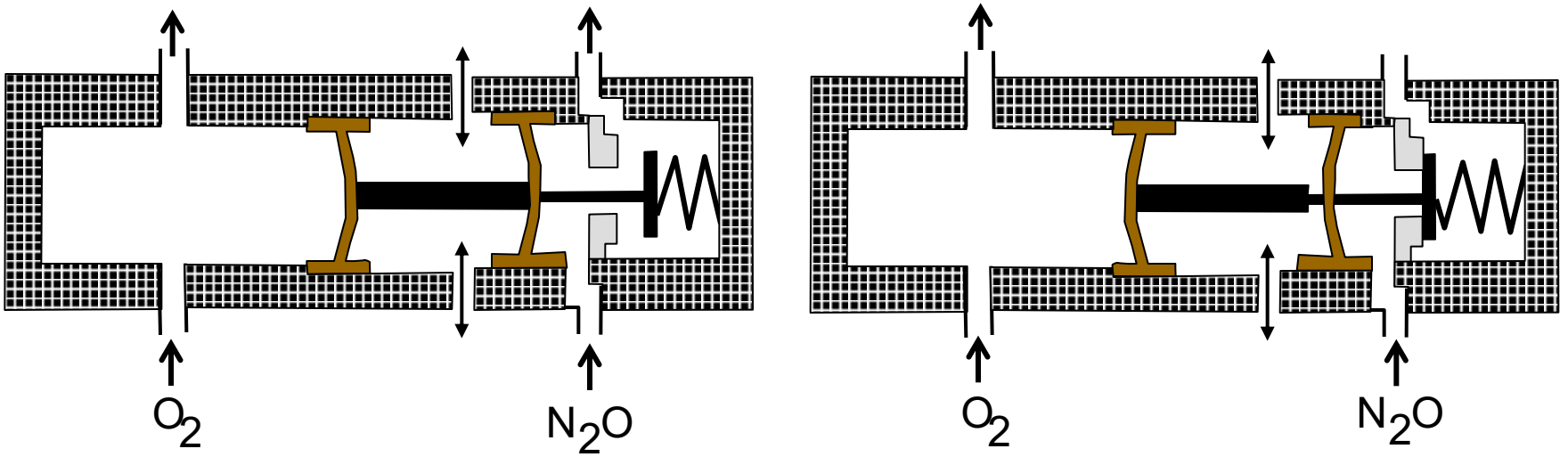
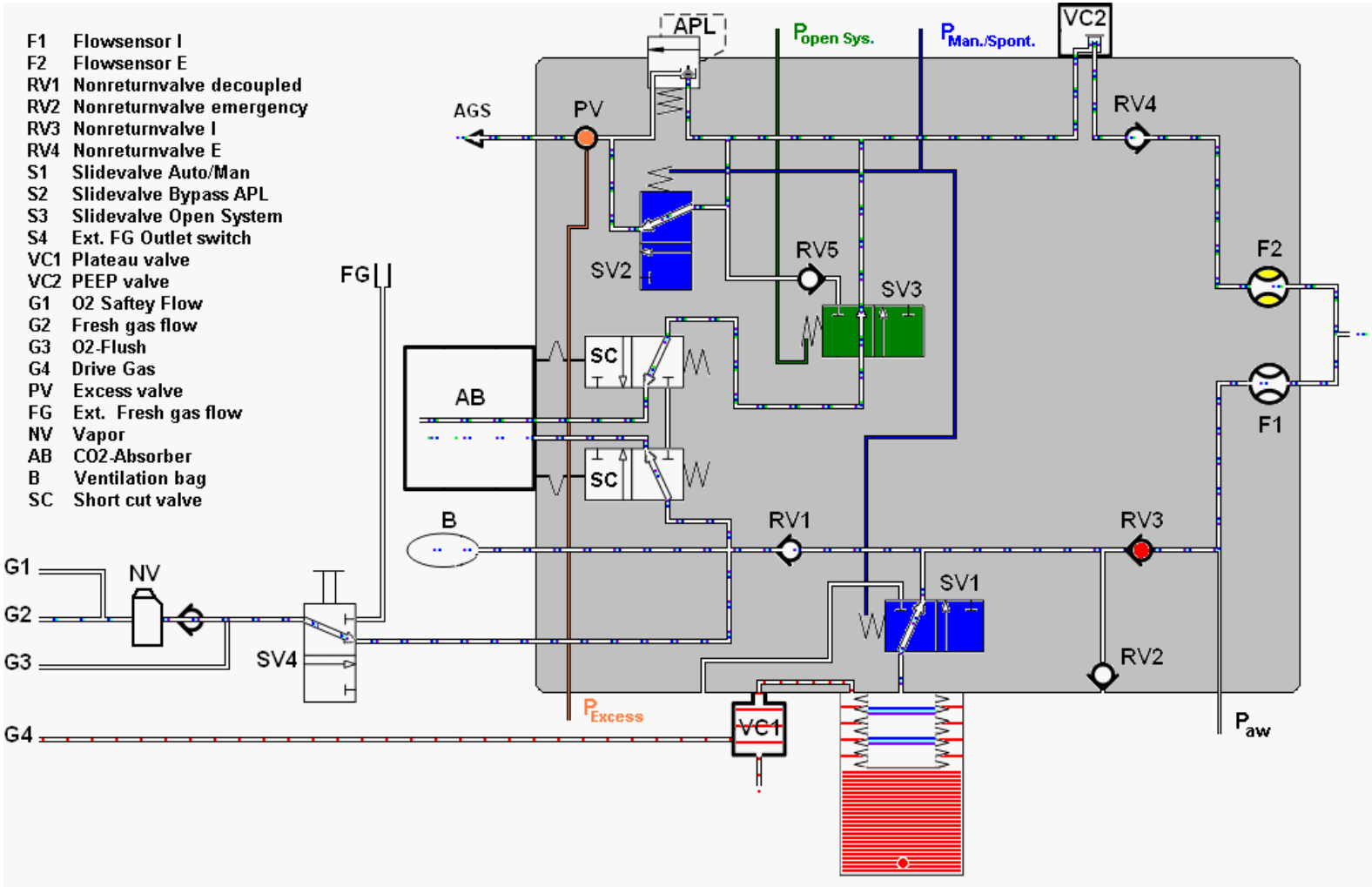
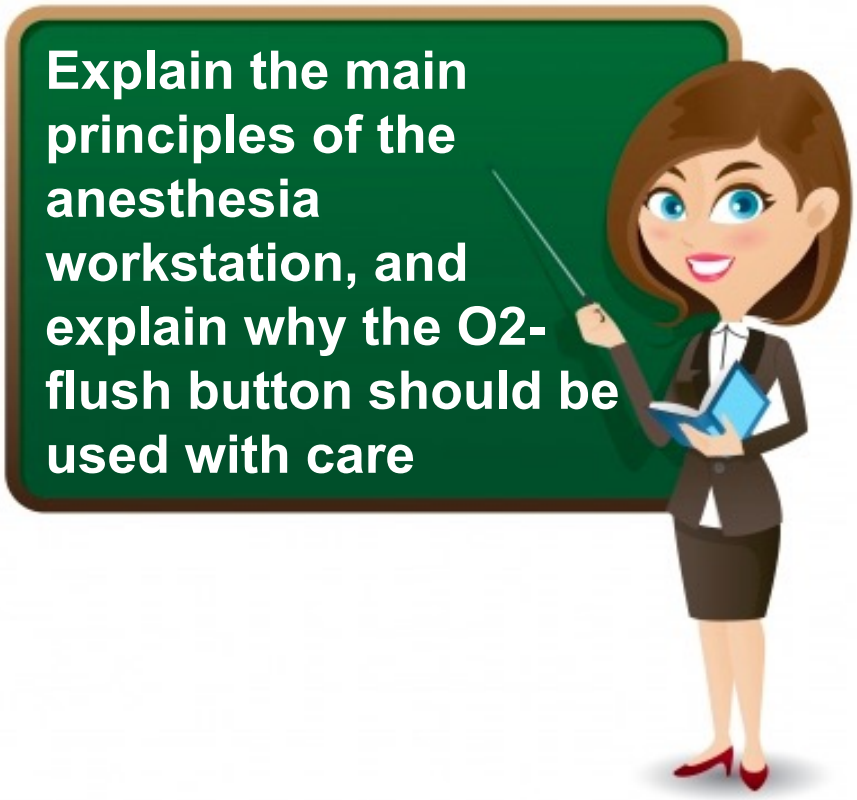


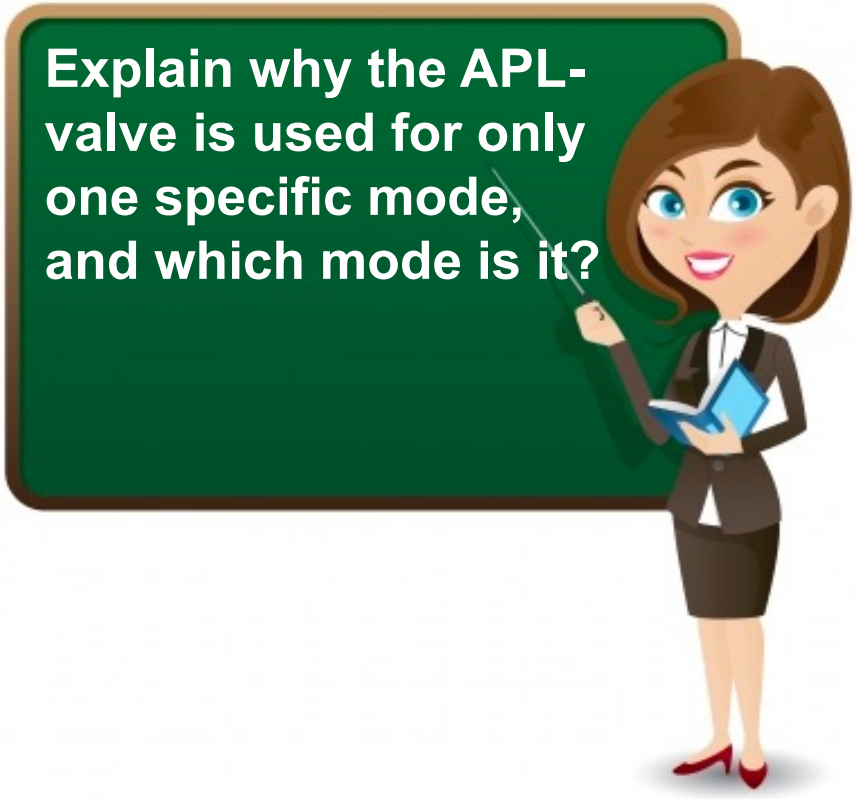
Fig. 2.F. 3-room slave regulator

Block diagram



Exercise examples







UiO : Department of Physics
University of Oslo

FYS 4250

Lecture 10

”Once a scout always a scout!”

UiO : Department of Physics
University of Oslo

Spectrophotometer



$$P = P_0 10^{-aLC}$$

P0 = radiant power arrivint at the cuvette
P = radiant power leaving the cuvette
a = absorptivity of the sample
L = length of the path through the sample
C = concentration of the absorbing substance

Hydrogen and deuterium lamps produce about 90% of their power in the infrared range
Tungsten: Progressively vaporizes from the filaments and condenses unevenly on the glass envelope

Wavelength selector: Filters and monochromators. Glassfilters used in applications in which modest accuracy is required
Monochromators utilize prisms and diffraction gratings = narrow bandwiths and adjustable wavelengths

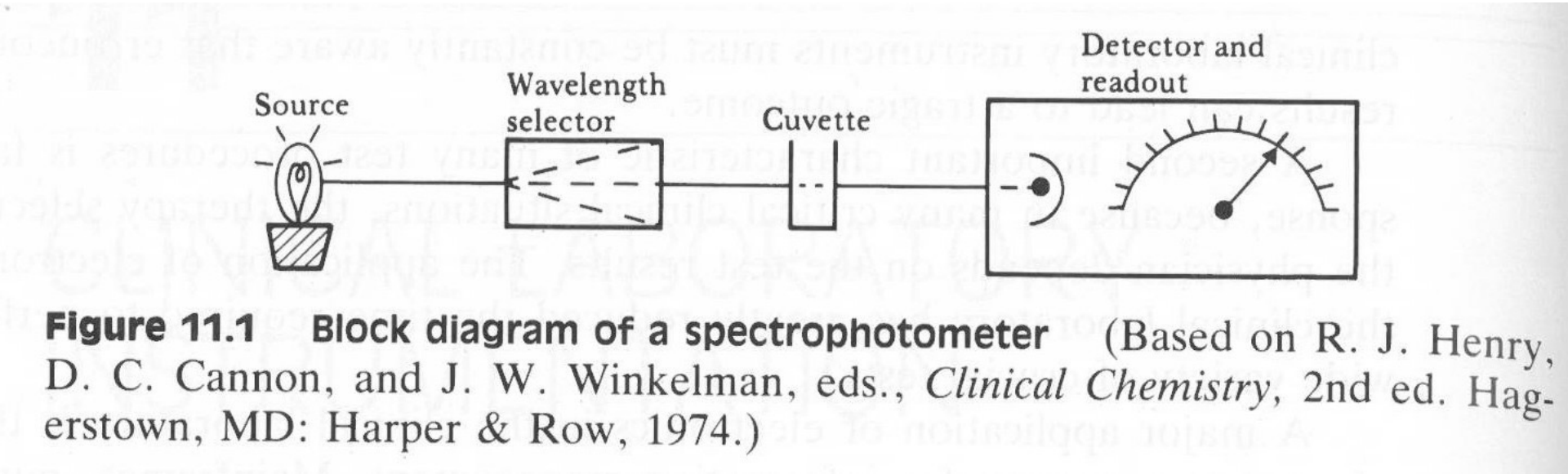
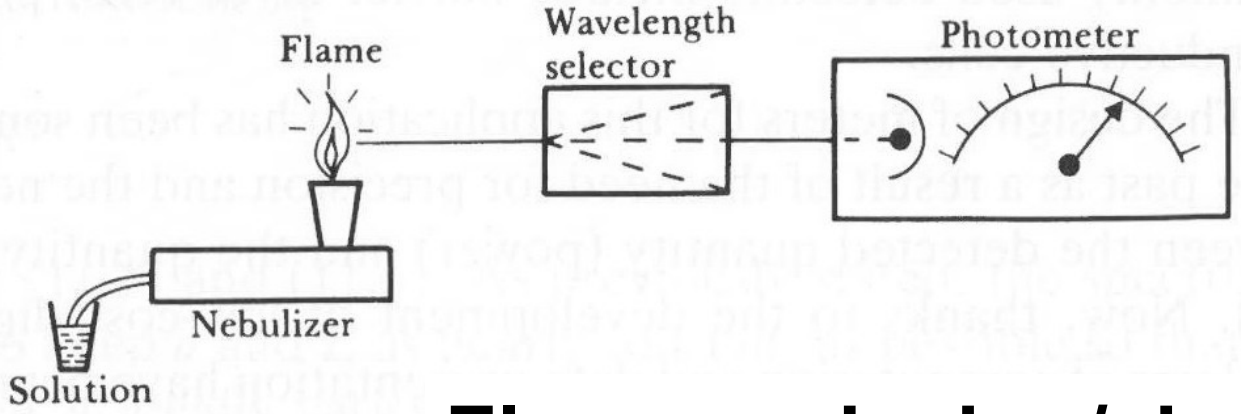
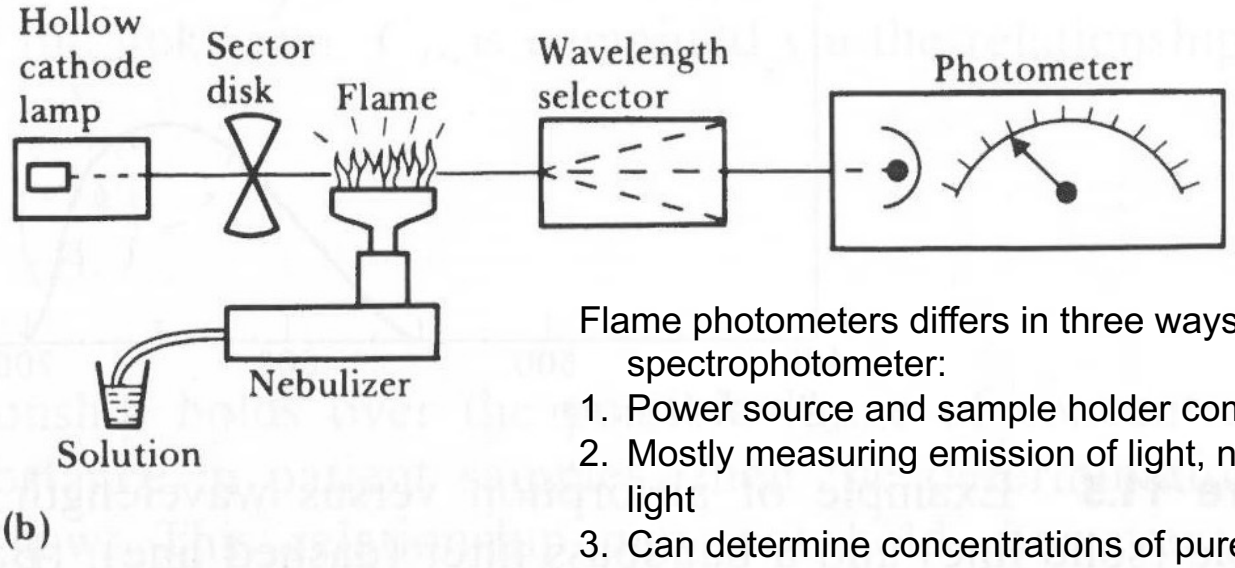


Figure 11.1 Block diagram of a spectrophotometer (Based on R. J. Henry, D. C. Cannon, and J. W. Winkelman, eds., *Clinical Chemistry*, 2nd ed. Hagerstown, MD: Harper & Row, 1974.)





Flame emission/absorption



Flame photometers differs in three ways from spectrophotometer:

1. Power source and sample holder combined in flame
2. Mostly measuring emission of light, not absorpion of light
3. Can determine concentrations of pure metal only

Figure 11.4 Block diagrams of instruments for (a) flame emission and (b) flame absorption. (Based on R. J. Henry, D. C. Cannon, and J. W. Winkelman, eds., *Clinical Chemistry*, 2nd ed. Hagerstown, MD: Harper & Row, 1974.)

Fluorometry

Advantage: High sensitivity
Disadvantage: Few substances have the property of fluroescense, Sensitivity to temperature and pH



Based on the fact that molecules emit light in a characteristic spectrum immediately after absorbing radiant energy and being raised to an excited state.

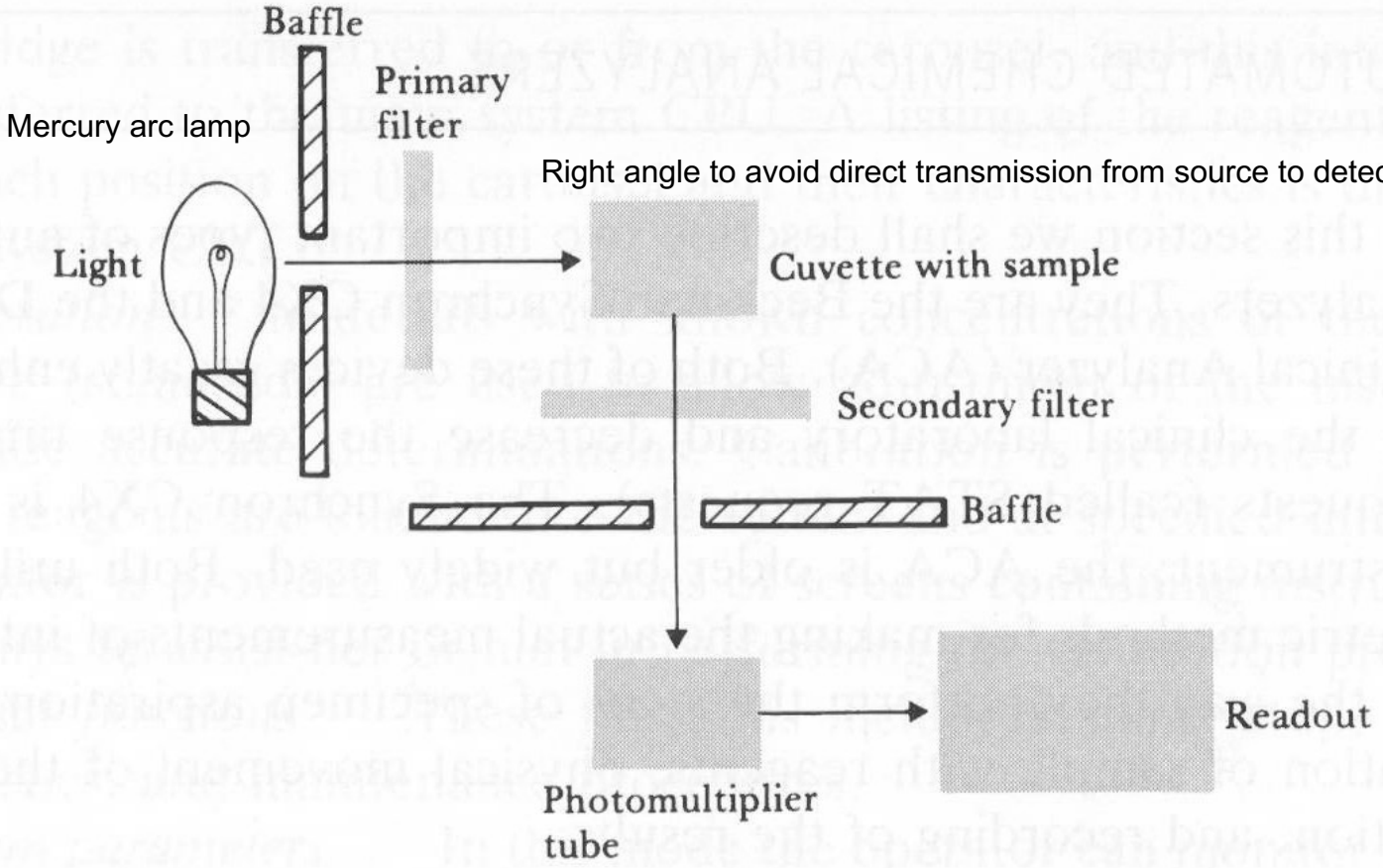
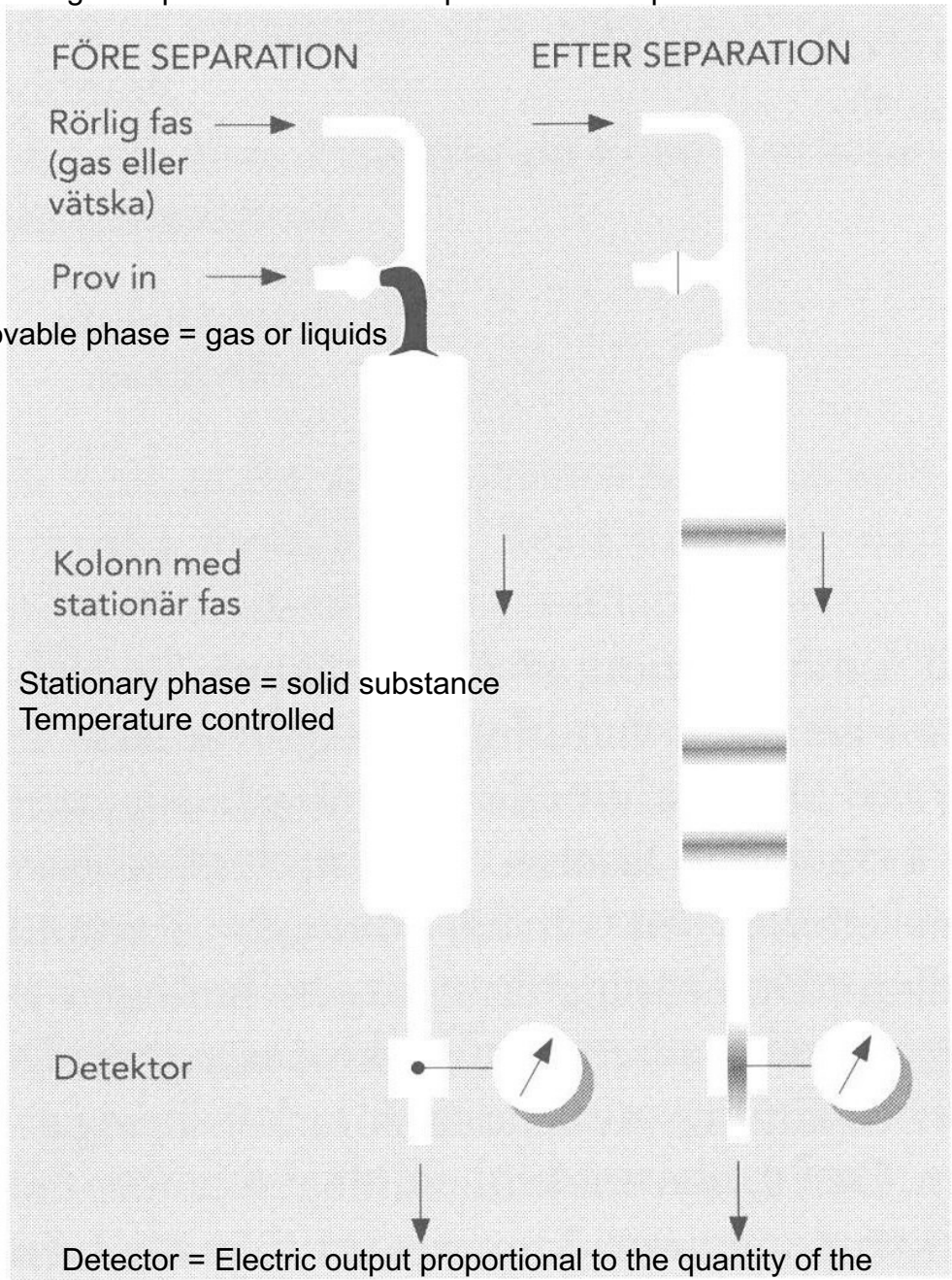


Figure 11.5 Block diagram of a fluorometer (From R. Hicks, J. R. Schenken, and M. A. Steinrauf, *Laboratory Instrumentation*. Hagerstown, MD: Harper & Row, 1974. Used with permission of C. A. McWhorter.)

High temperature to flash evaporate the sample and solvents



Movable phase = gas or liquids

Stationary phase = solid substance
Temperature controlled

Detector = Electric output proportional to the quantity of the compound in the effluent gas

Gas/liquid cromatography

(GLC)

Used for separating mixture of substances into component parts

Carrier gas = inert gas, sweeps the evaporated sample and solvent gas down the column

Advantages = Speed, ability to operate with a small amount of sample and great sensitivity

Figur 5:14. Princip för kromatografi. Separation av provets komponenter sker genom utnyttjande av att de har olika vandringshastighet, då en rörlig fas flyter fram över en stationär fas.

UiO : Department of Physics
University of Oslo

Electrophoresis

Charged particles migrate in response to an electrical field

- Field strength
- Charge
- Size
- ++



Mobility = distance in centimeters a particle move in unit time per unit field strength, expressed as voltage drop per centimeter

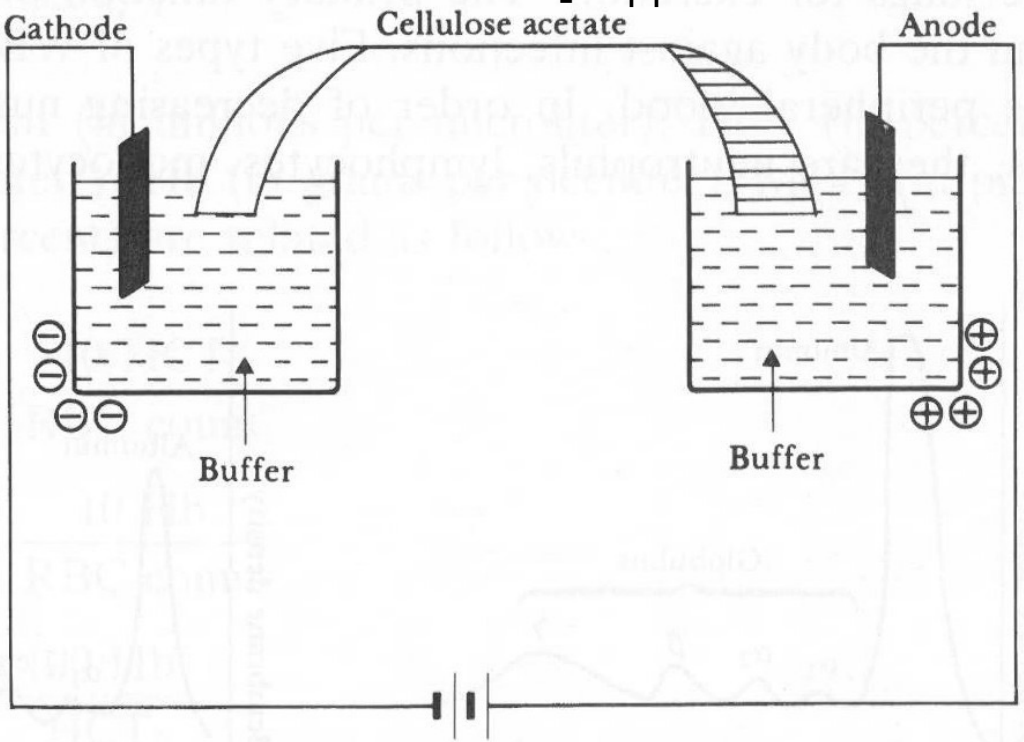


Figure 11.11 Cellulose acetate electrophoresis (From R. Hicks, J. R. Schen-

Typical = various proteins in blood and nucleic acids, csf ++
Defined as the movement of a solid phase with respect to a liquid (buffer solution).
Buffer -> carry current and keep the pH constant
Electrid field -> particles similar in charge, size and shape migrate at similar rates directly related to the net magnitude of the particle's charge
Disadvantage = temperature dependency
Advantage = Rapid and highly sensitive

Coulter counter cell counter

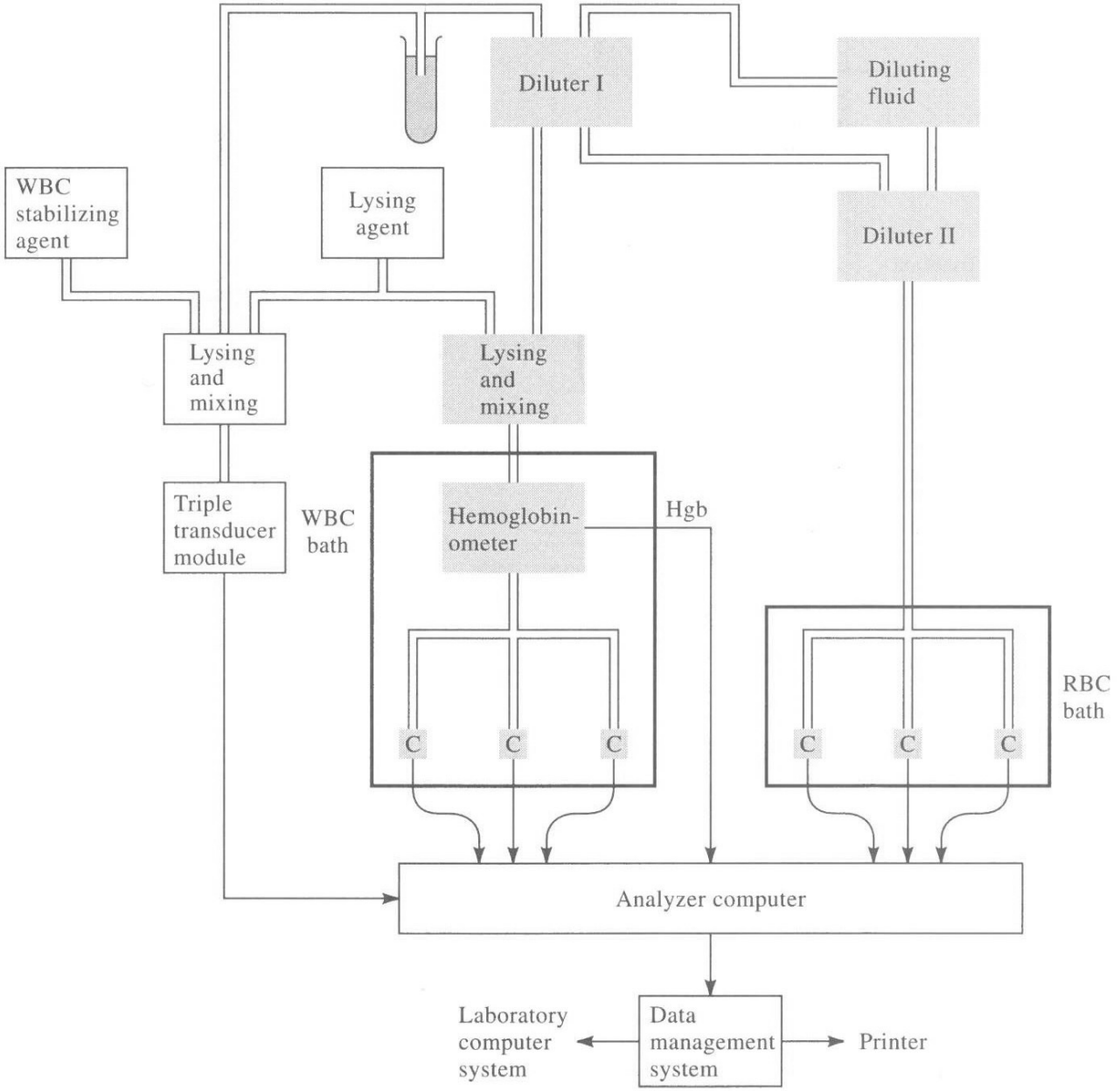


Figure 11.11 **A block diagram of a Coulter Model STKS.** (Modified from J. Davidsohn and J. B. Henry, Todd Sanford Clinical Diagnosis by Laboratory Methods, 15 ed. Philadelphia: W. B. Saunders Co.)

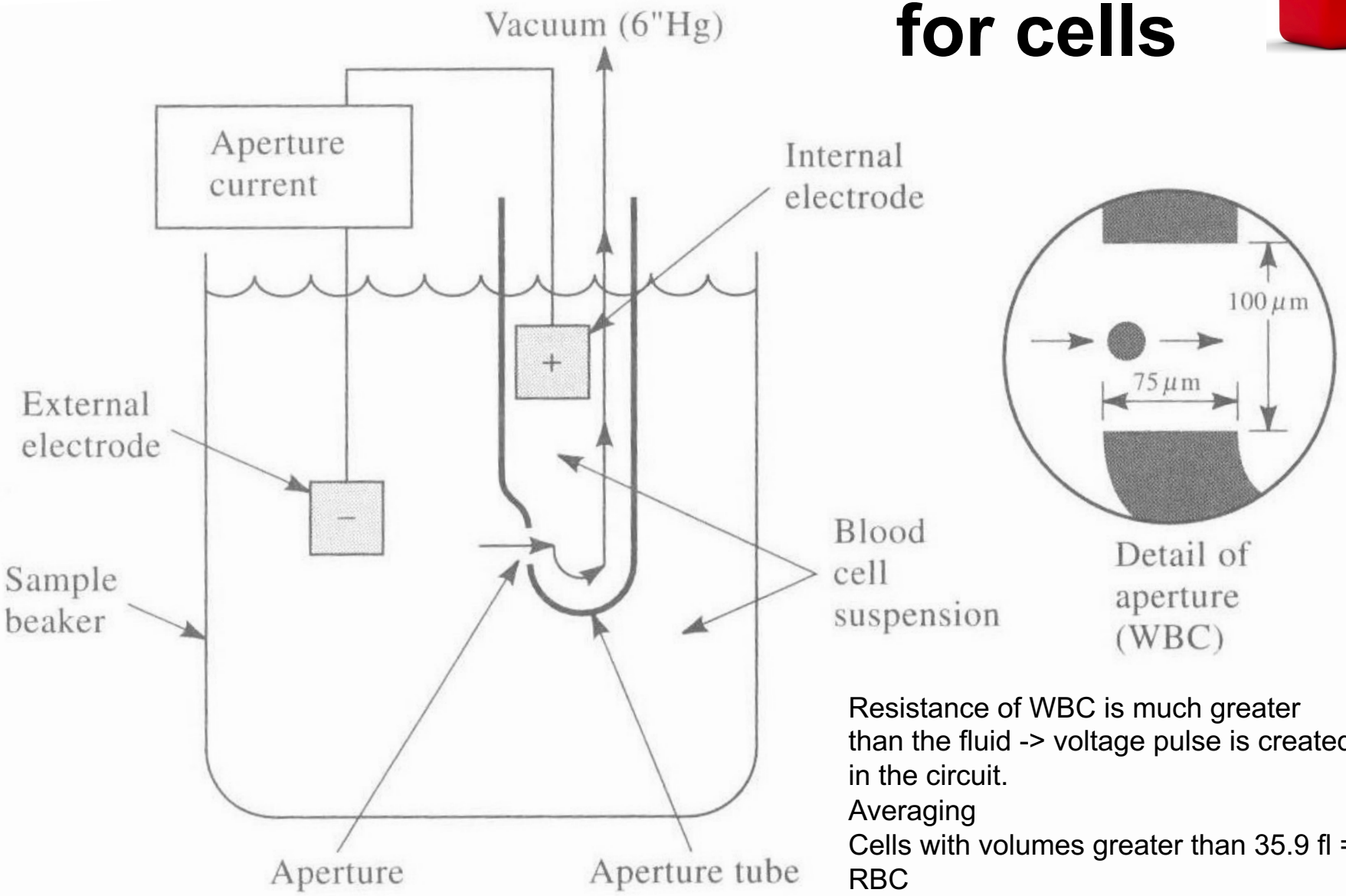
Hematology:
RBC, WBC and plateles
Anticoagulants

Lyzing agent causes cell membranes of RBC to rupture and release HGB

Ratio WBC vs RBC 1:600
1% of the blood vs 36-50% of the blood

Impedance- detector for cells



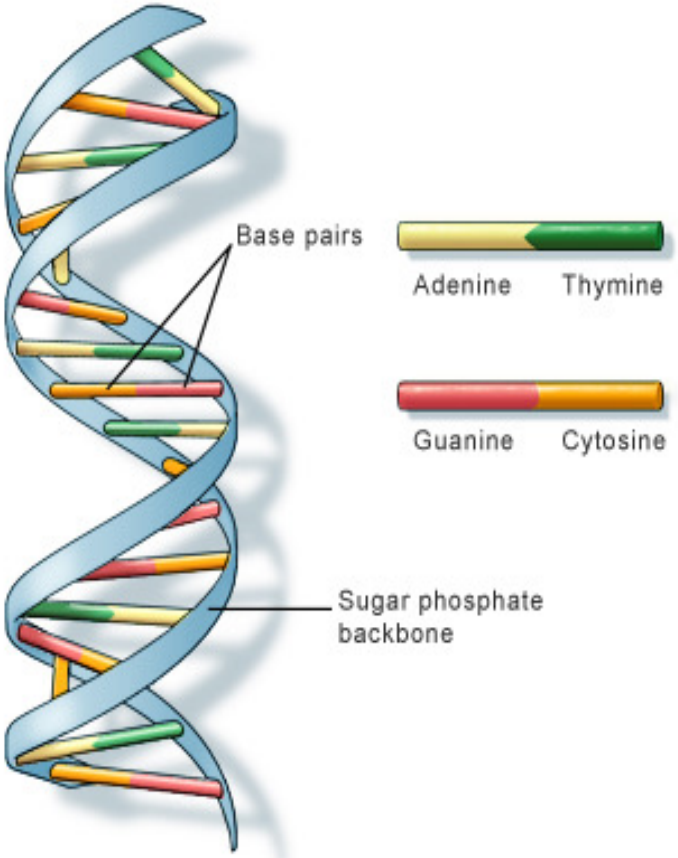


Resistance of WBC is much greater than the fluid -> voltage pulse is created in the circuit.
Averaging
Cells with volumes greater than 35.9 fl = RBC

Figure 11.12 Coulter STKS aperture bath.

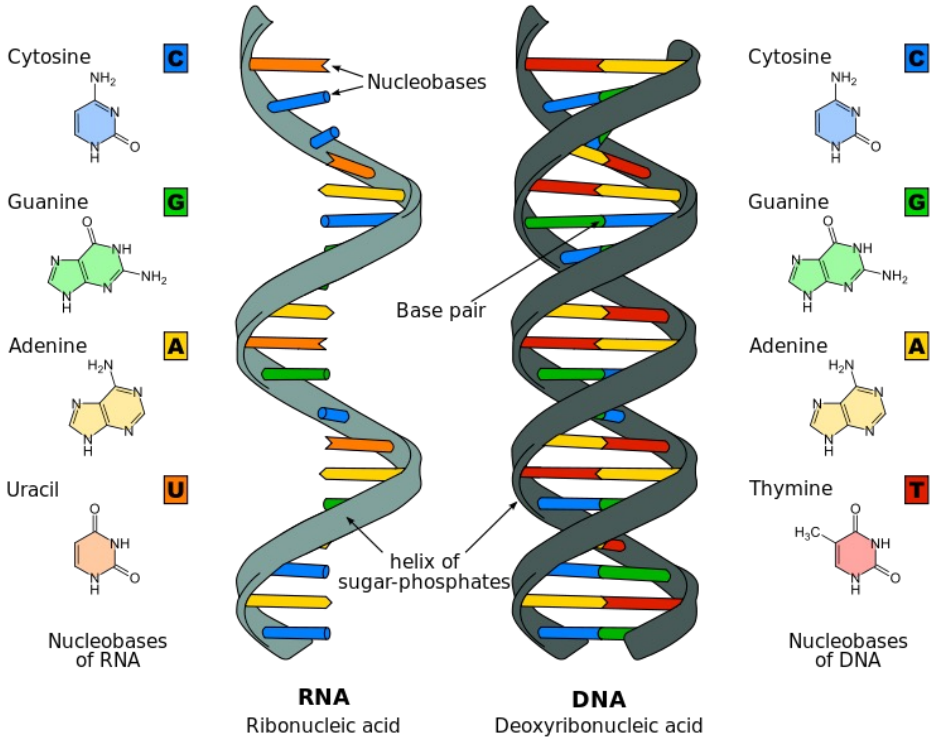
Deoxyribo Nucleic Acid (DNA)

- A double helix built of nucleotides, connected to long chains
- Base pairs of Adenine (A), Thymine (T), Guanine (G) and Cytosine (C). Guanine will always combine with Cytosine, and Thymine will always bind with Adenine.
- Backbone contains sugar-phosphate
- Each triplet of ATGC codes for a certain amino acid that will build a protein
- The genetic code is determined of the order of the nitrogenbases in the DNA-chain, the so called genetic code



Ribo Nucleic Acid (RNA)

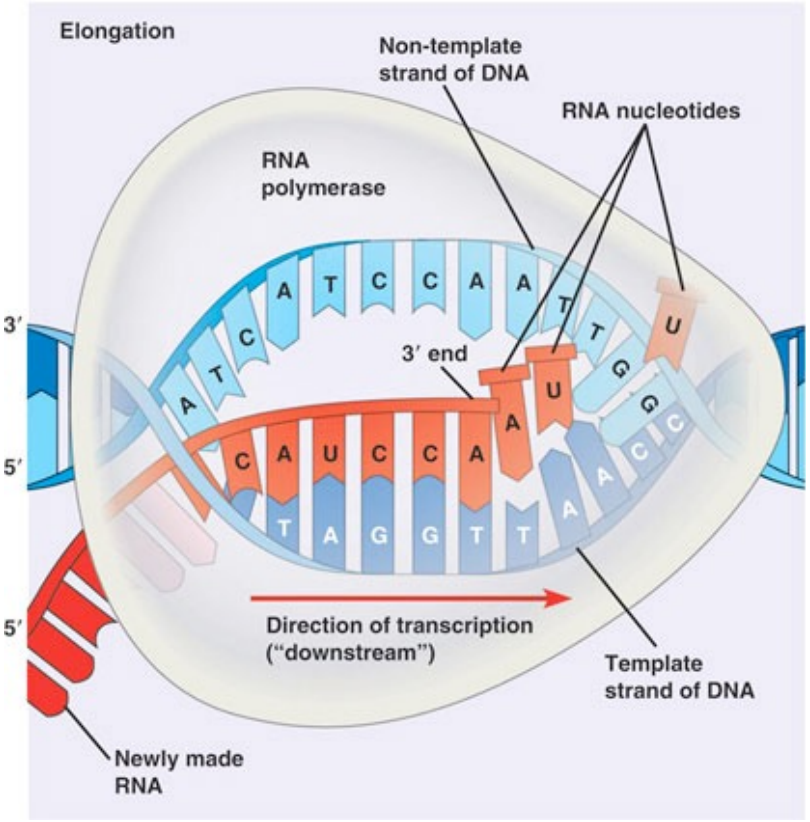
- DNA contains all the necessary information for protein synthesis, but the job is done in the ribosomes
- DNA molecules are too big to penetrate the nucleus-membrane, transcription gives m-RNA that can move freely into cytosol
- RNA is an information transference of the DNA into the ribosomes where amino acids are connected to form proteins
- ACG are the same as for DNA, but thymin is replaced with Uracil (U)



http://upload.wikimedia.org/wikipedia/commons/thumb/3/37/Difference_DNA_RNA-EN.svg/749px-Difference_DNA_RNA-EN.svg.png

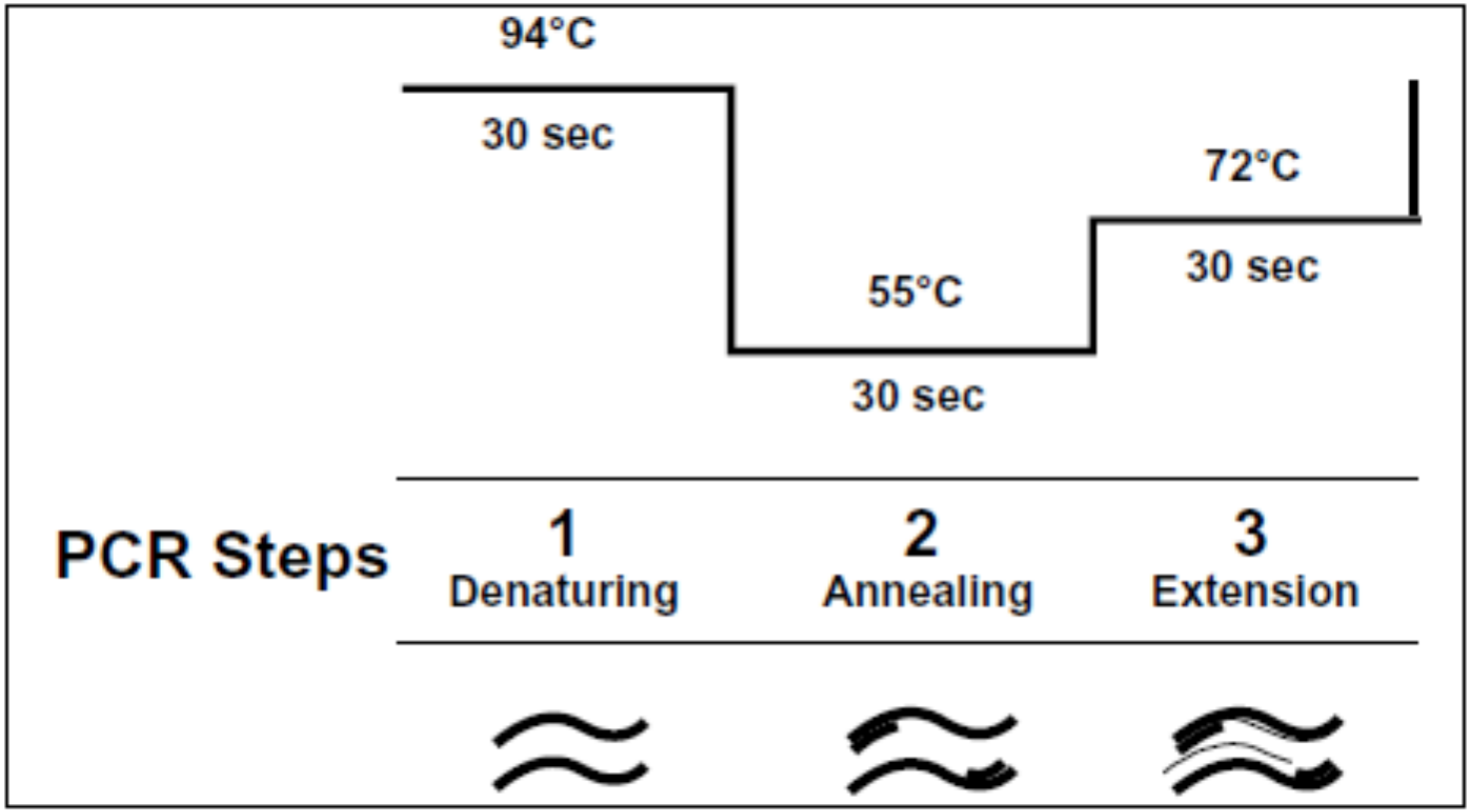
M-RNA syntesis

- The two DNA-chains are separated in order to release the nitrogen bases. RNA polymerase binds free ribonucleotides complementary to the nucleotides in the DNA-chain
- Each triplet in DNA gives a complementary triplett in m-RNA
- At the start of each gene there is a promotor defining the starting point of the polymerase
- t-RNA connects to specific amino-acids and if the m-RNA code is matched, this can be used by the ribosome for decoding the m-RNA and building chains of amino acids



http://meyerbio1b.wikispaces.com/file/view/transcription.jpg/72711585/transcription.jpg

The three cycles of PCR

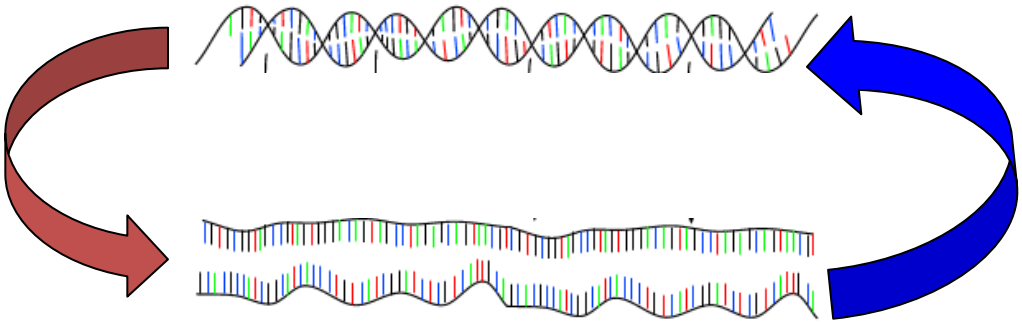


Palumbi: The simple fool's guide to PCR



Denaturation - Renaturation

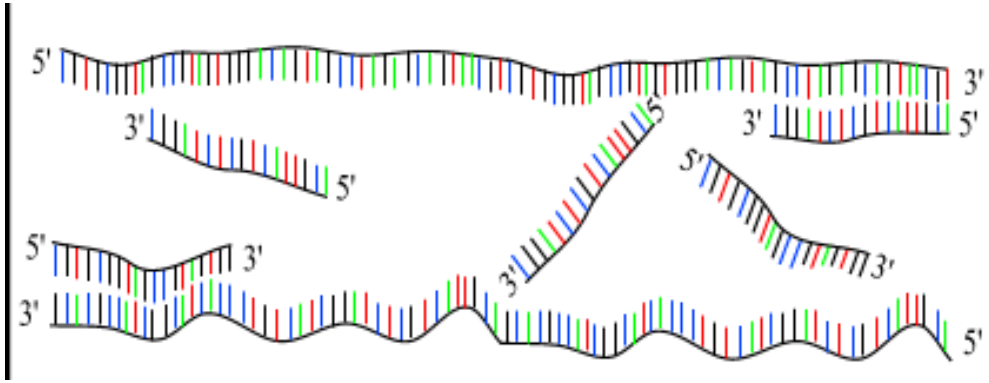
- Separating the double helix DNA by applying heat = Denaturation
- Careful cooling anneals the helix = renaturation
- All DNA becomes single strands





Annealing

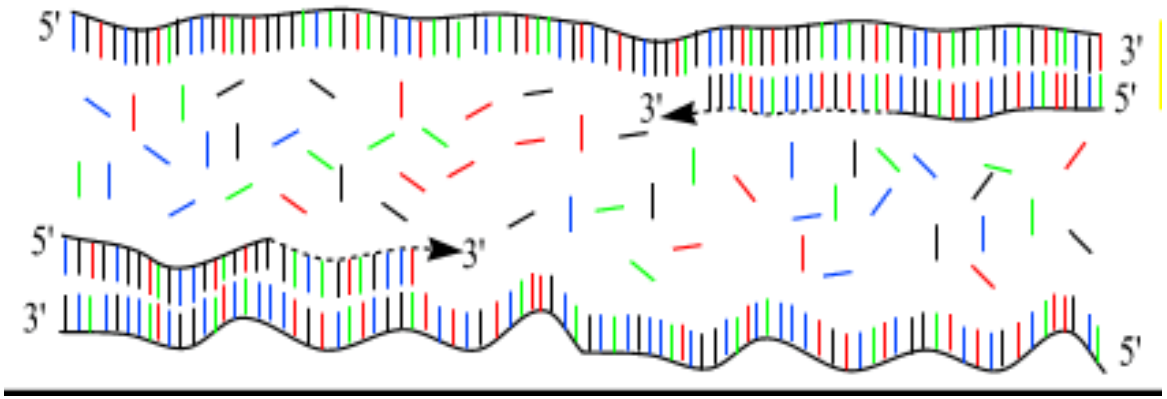
- In order to bind to each of the complementary regions, two primers are supplied in molar excess
- Temperature is lowered to allow primers to anneal. (Too low temperature will allow randomly annealing, too high temperature will avoid any binding at all)
- Typically temperature between 40 – 60 degrees C



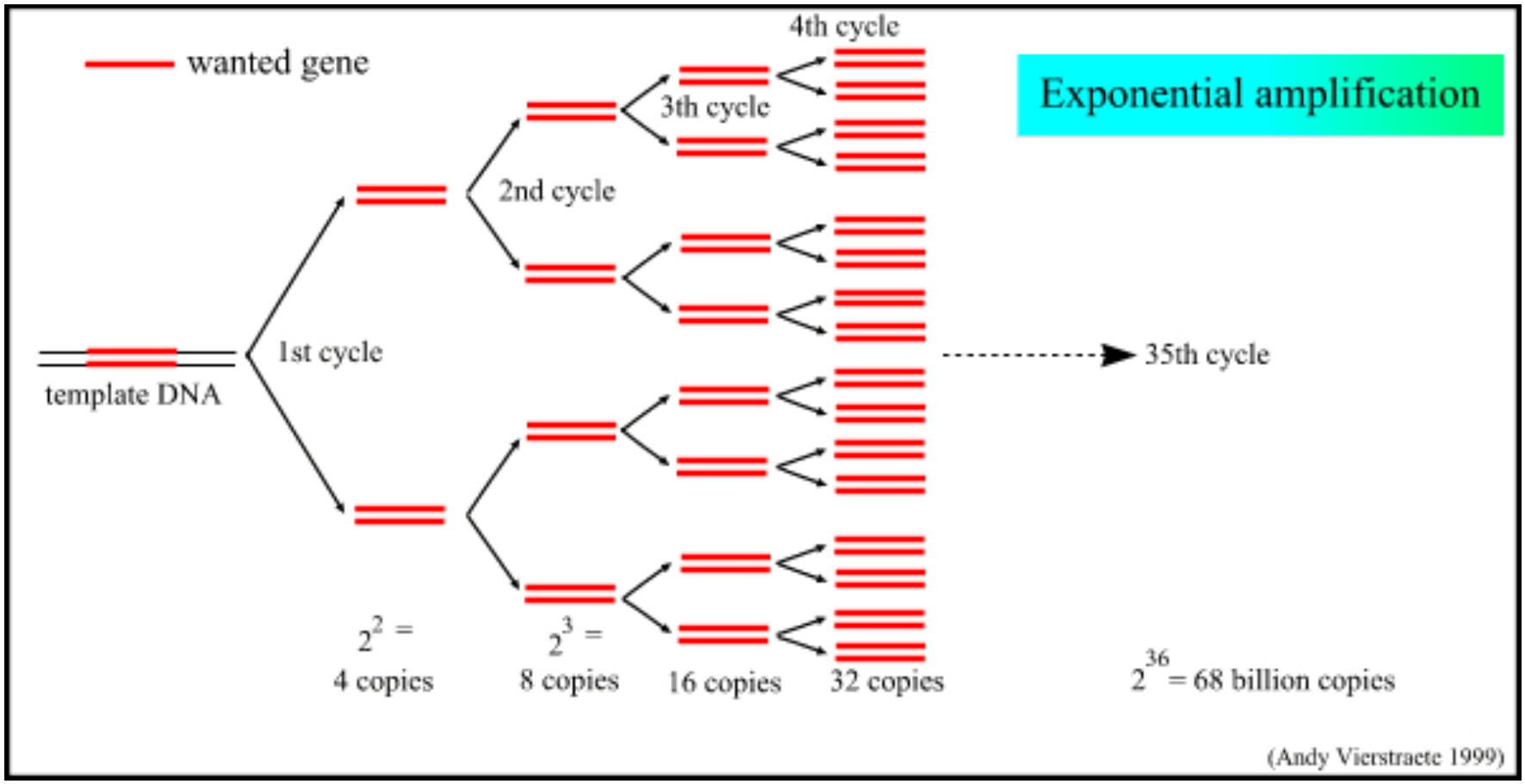


Extension

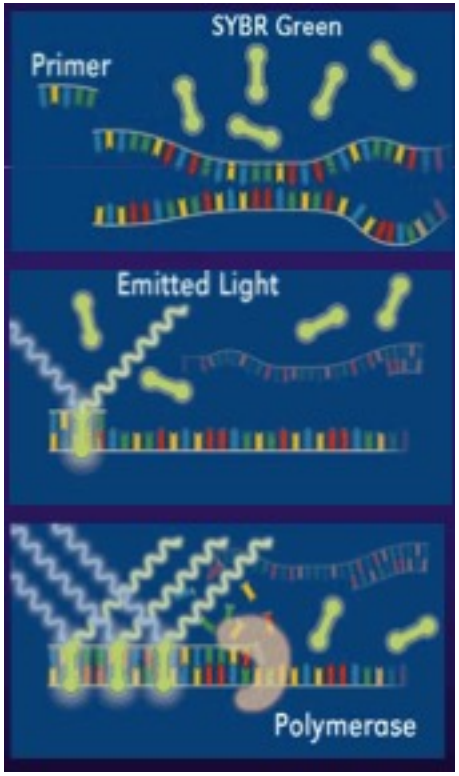
- DNA polymerase duplicates DNA, typically between 72-75° C for maximal polymerase function.
- Polymerase must add nucleotides to the 3' end of the primer sequence annealed to the template DNA
- Primers are critical for the initiation of the reaction



PCR amplification

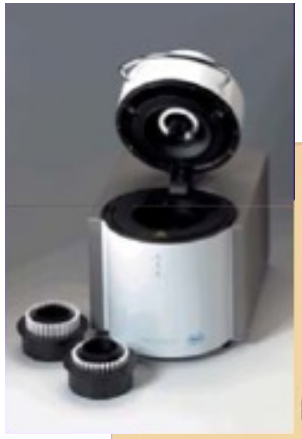


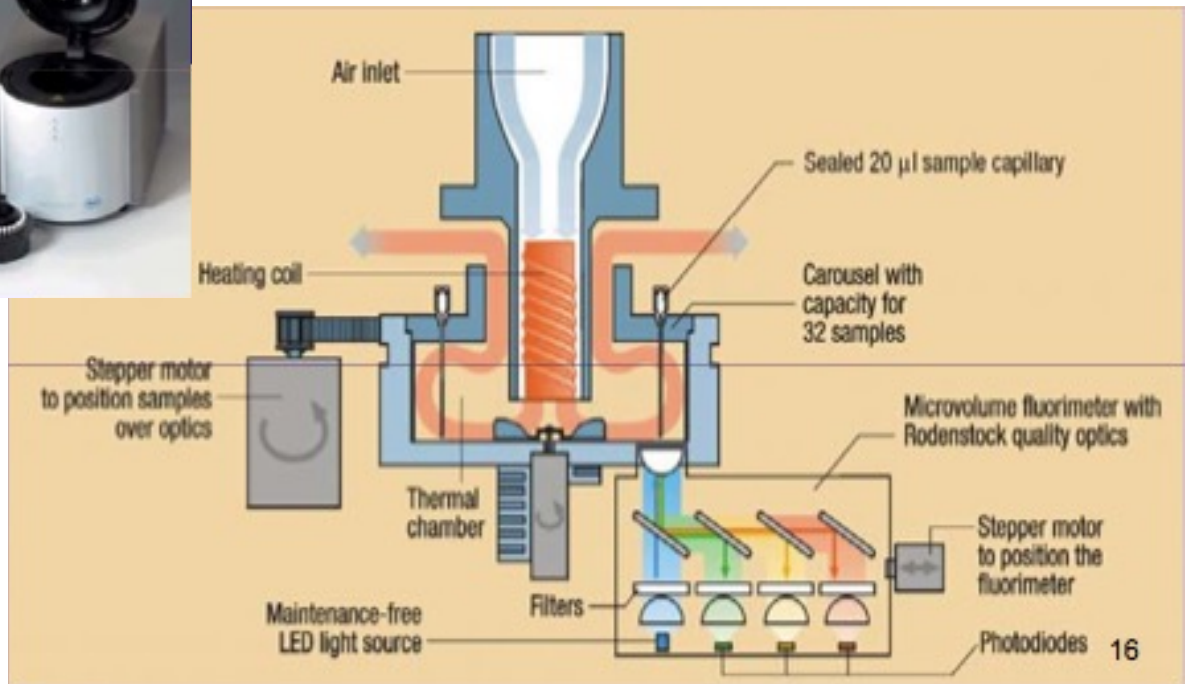
Real-time qPCR



Source:Viraphong Lulitanond, Ph.D.

Real-time qPCR





Source:Viraphong Lulitanond, Ph.D.



Advantages and disadvantages with PCR

Adv:

- Extremely sensitive, can amplify the DNA of interest from one single cell (Even for old, degraded DNA)

Disadvantage:

- The sensitivity. If contamined, the contaminated DNA will also be amplified.



Advantages with Real-time PCR (qPCR)

- Identify amplified fragments during the PCR process (exponential phase, traditional PCR measures during the plateau phase) = a good measurement of the starting quantity of the material

- Standard PCR requires post-PCR analysis (typ electrophoresis), possibly agarose gel electrophoresis;. Real-time PCR eliminates these needs. Amplicon recognition is achieved by monitoring the accumulation of specific products during each cycle.

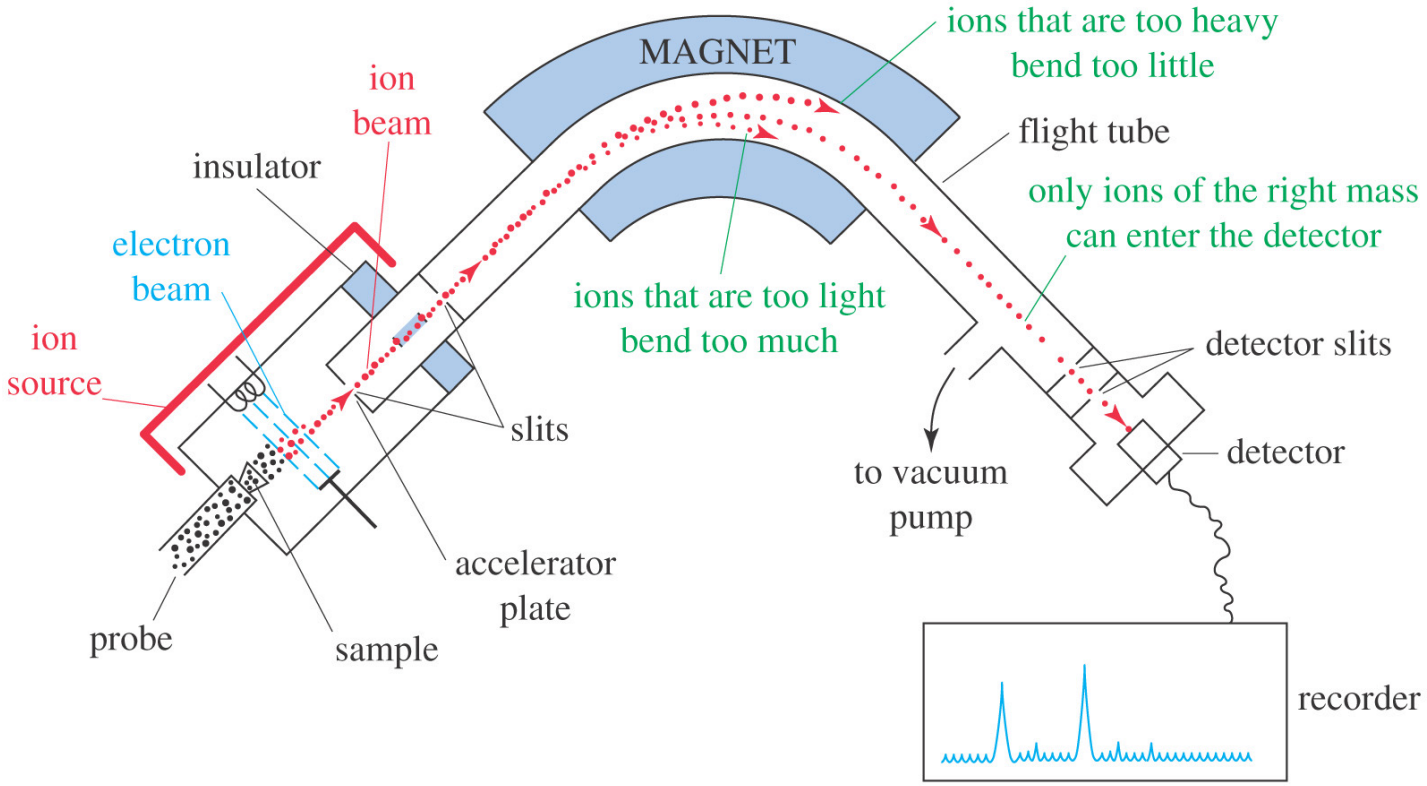
- qPCR is performed in the same tube for the whole prosess. Regular PCR is transferred to other formats = increased risk of contamination

Mass spectrometry



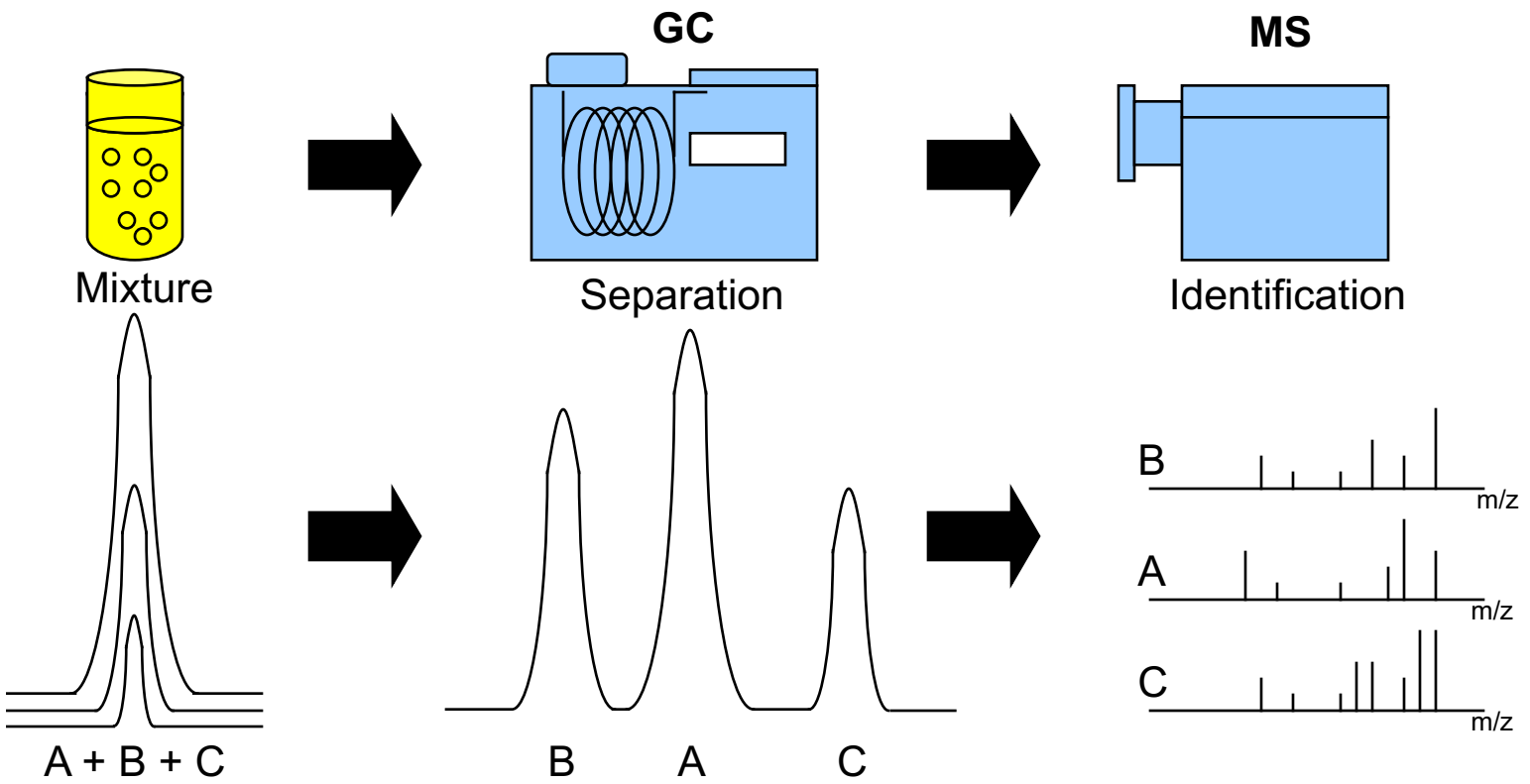


Mass spectrometry

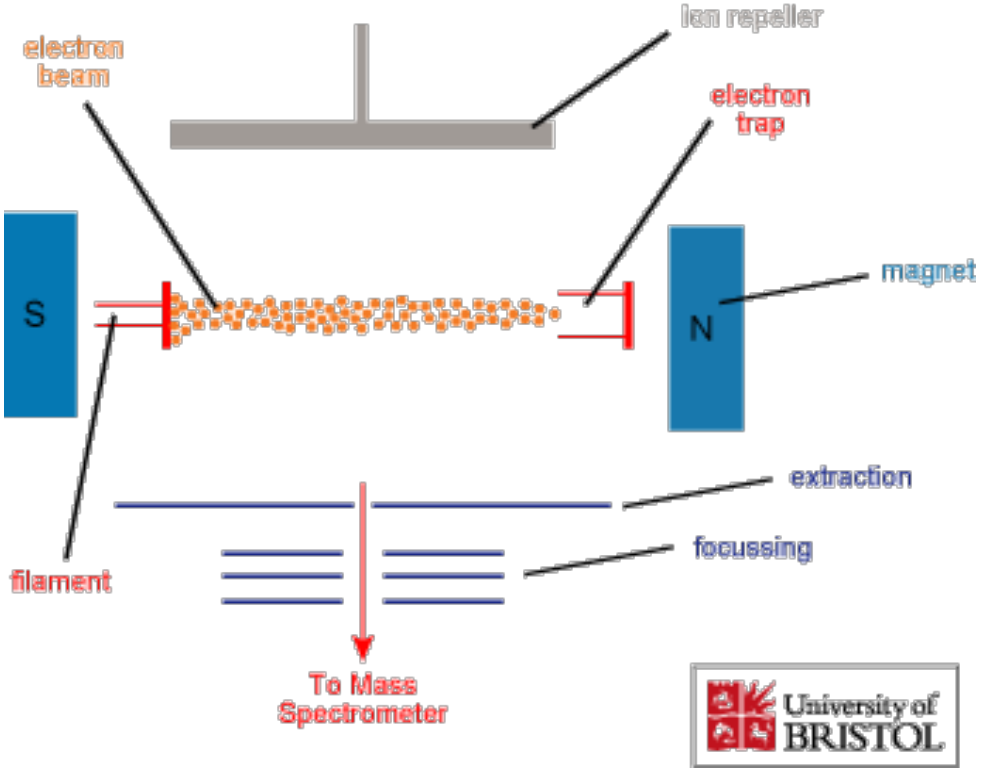


Copyright © 2005 Pearson Prentice Hall, Inc.

Analysis by GC-MS



Electron impact ionization (EI)



Bombardment with high-energy electrons, typically 70 eV.
Due to collision, an electron is removed from the analytes (M), which results in a molecular ion M+.

$M + e \rightarrow M^+ + 2e^-$

Scan mode or SIM mode

- There are two options: Look for a single ion (SIM) or perform a wide scan (SM).
- Scan mode means that the mass filter is adjusted to allow a wide range of masses pass through. A spectrum is obtained for all the different masses
- Scan mode is less sensitive due to the loss of ions in the quadropole rods
- Sim mode increases sensitivity and is typically used for quantitative analysis
- In SIM mode, you need to know the desired specimen that should be monitored

Advantages and disadvantages with MS

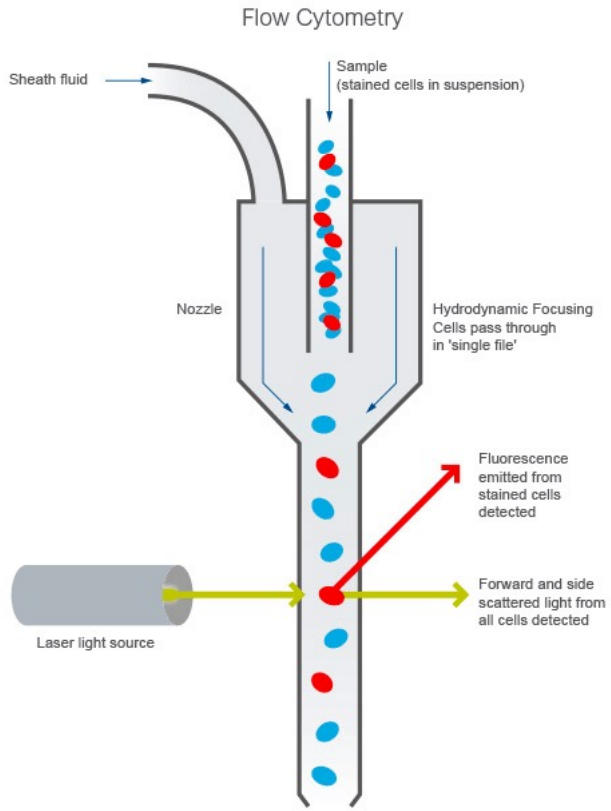
advantages:

- Relatively fast process
- Small sample size
- Can differentiate between isotopes

Disadvantages:

- No directly structural information (can often be derived though)
- Only for pure compounds
- Non-volatile compunds are difficult, only gas-phase ions are accepted
- destructive technique

Overview flowcytometer

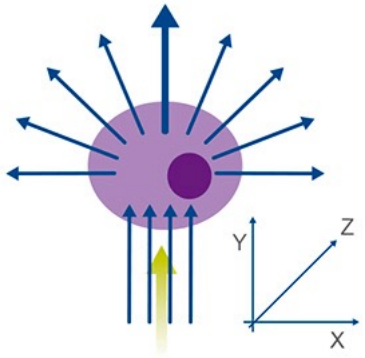


The fluid will focus the cell suspension so that the cell will pass the laser, one cell at a time

https://www.abcam.com/protocols/introduction-to-flow-cytometry



Overview flowcytometer



When the green laser interrogates the cell, light will scatter. The cell size and granularity will determine the direction of the scattered light.

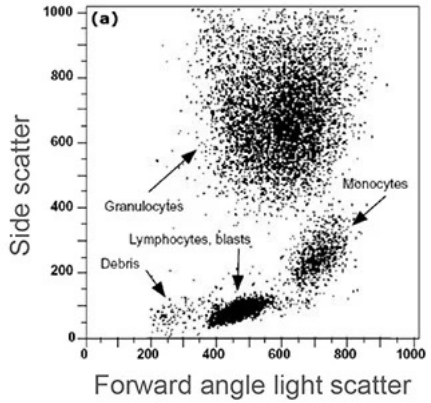
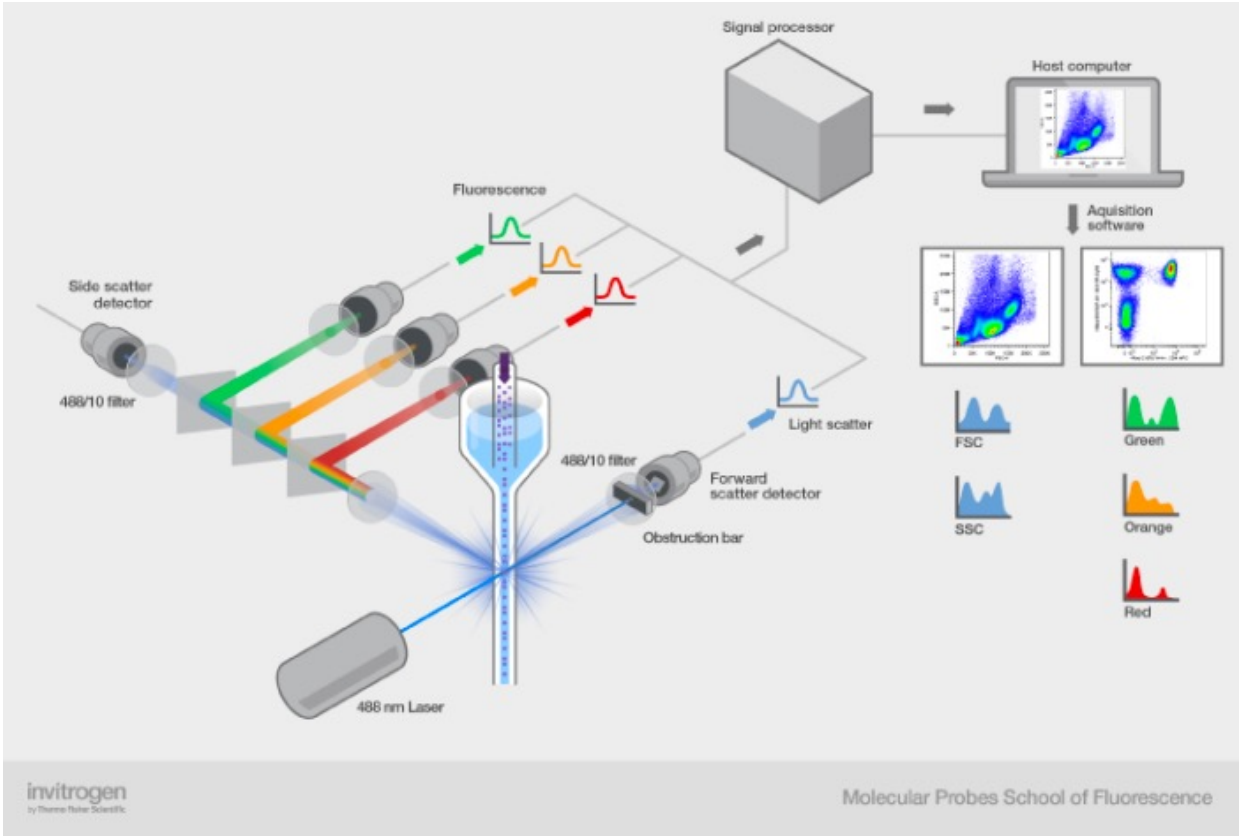


Figure 3. Dot plot of FS versus SS. *Each dot represents a single cell analyzed by the flow cytometer. The characteristic position of different cell populations is determined by differences in cell size and granularity. Image reference: Riley and Idowu. Principles and Applications of Flow Cytometry**

https://www.abcam.com/protocols/introduction-to-flow-cytometry

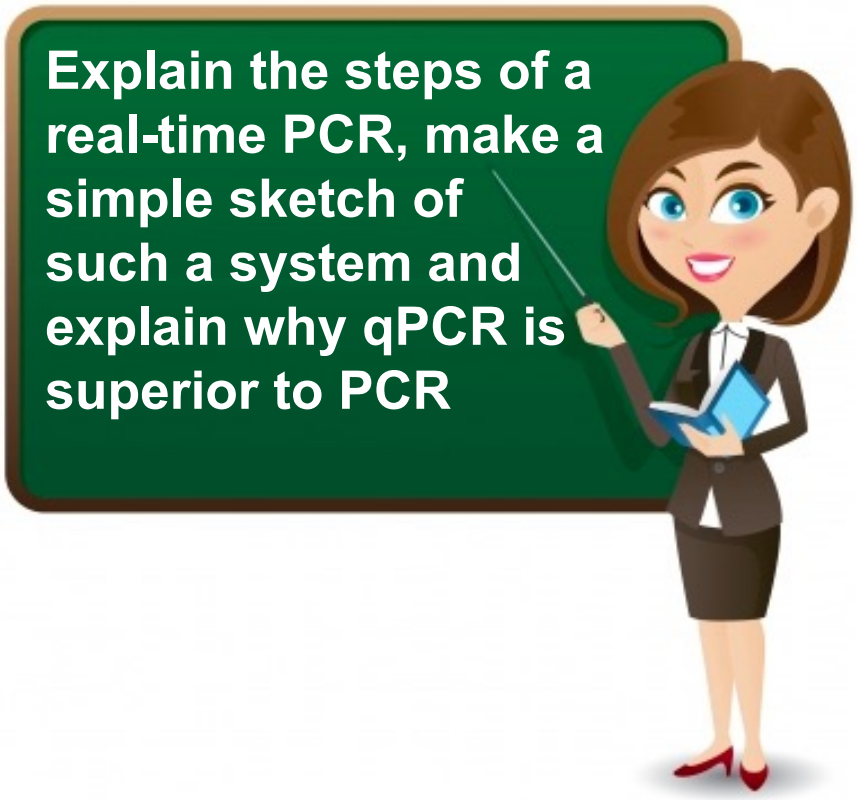


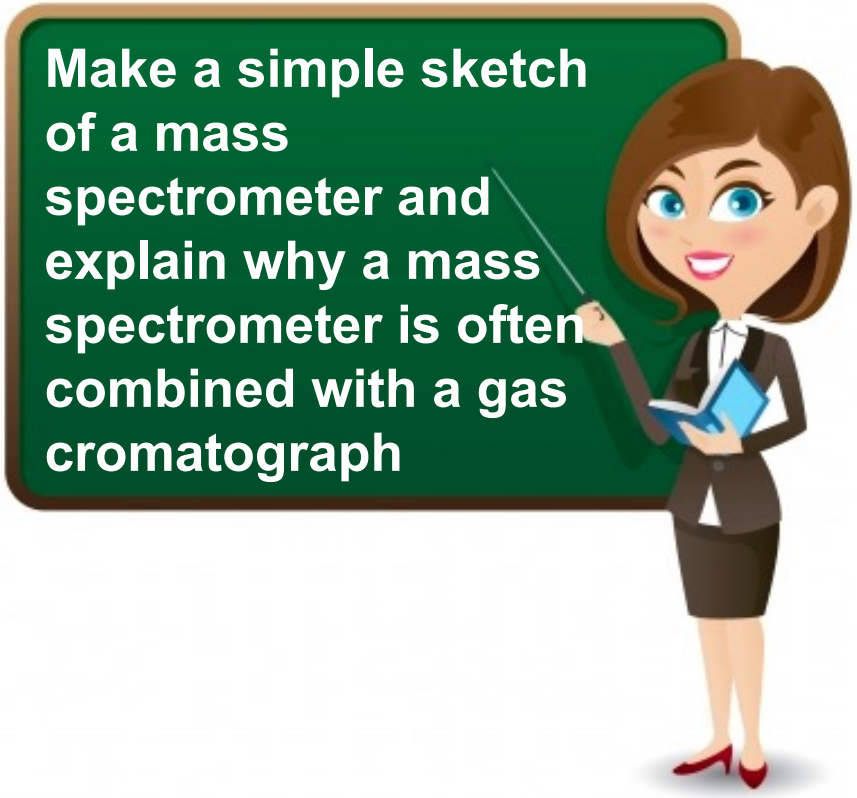
Overview flowcytometer



https://www.thermofisher.com/uk/en/home/life-science/cell-analysis/cell-analysis-learning-center/molecular-probes-school-of-fluorescence/flow-cytometry-basics/flow-cytometry-fundamentals/how-flow-cytometer-works.html

Exercise examples







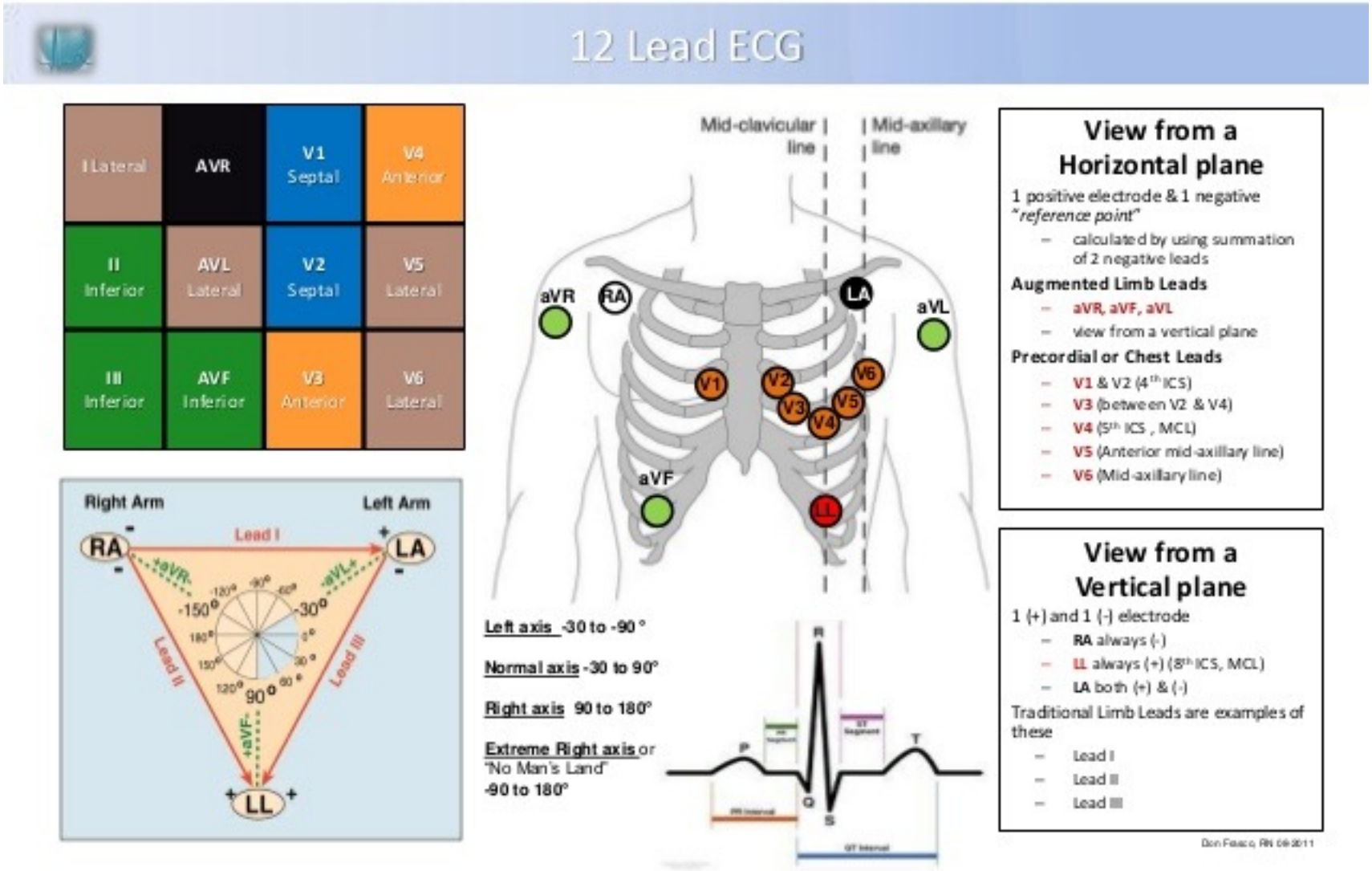
UiO : Department of Physics
University of Oslo

FYS 4250

Lecture 11

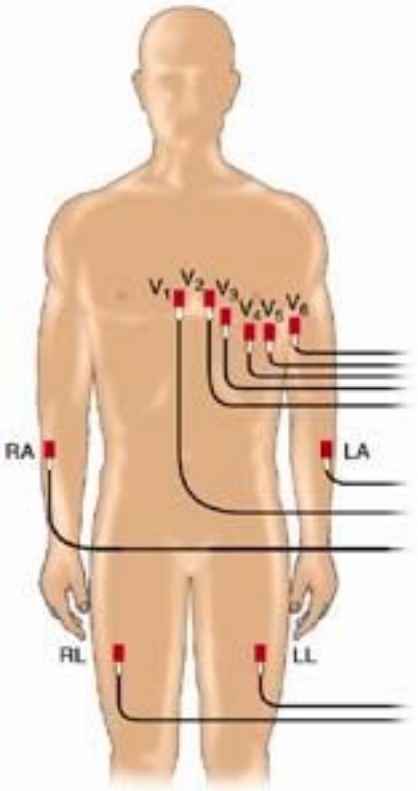
An accident rarely comes alone…

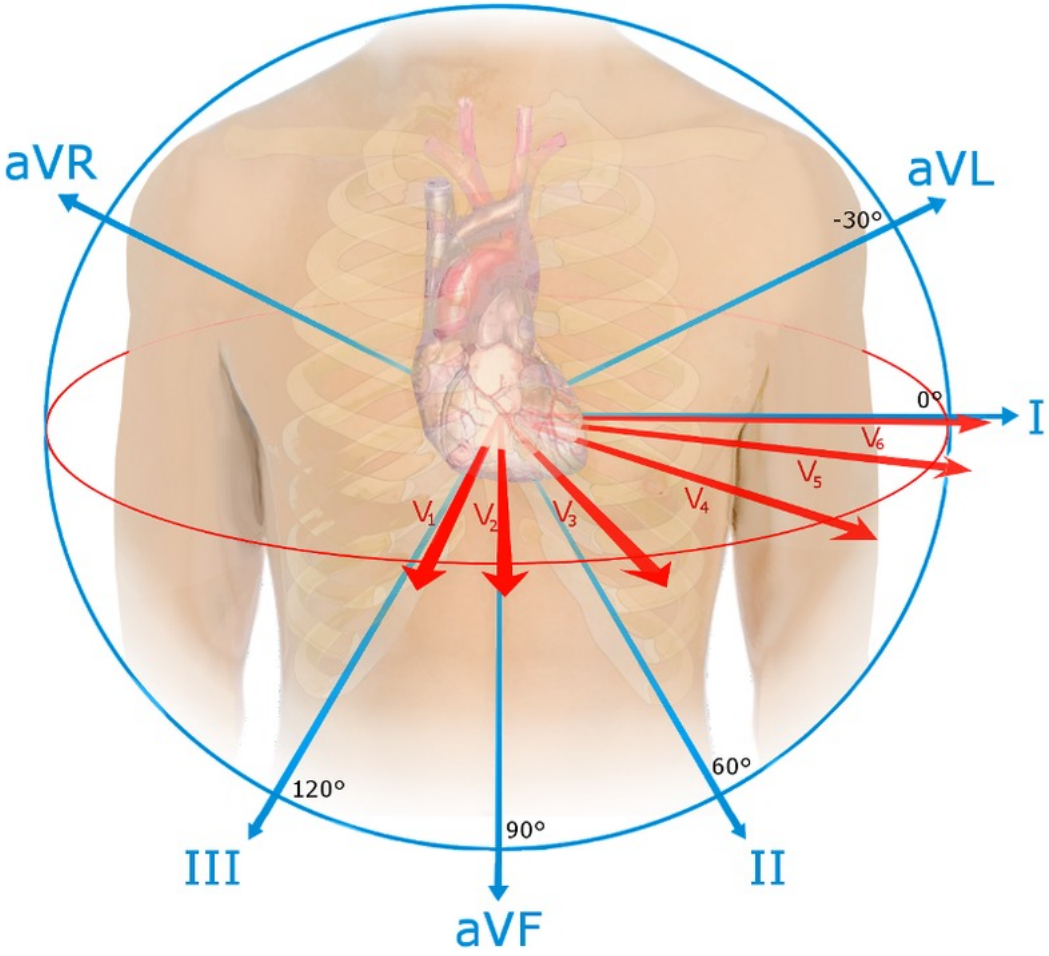
12-lead ECG



http://image.slidesharecdn.com/12-lead-ecg-hss-student-handout-ed-08-2011-2-121121182917-phpapp01/95/12-lead-handout-1-638.jpg?cb=1353522589

12-lead ECG



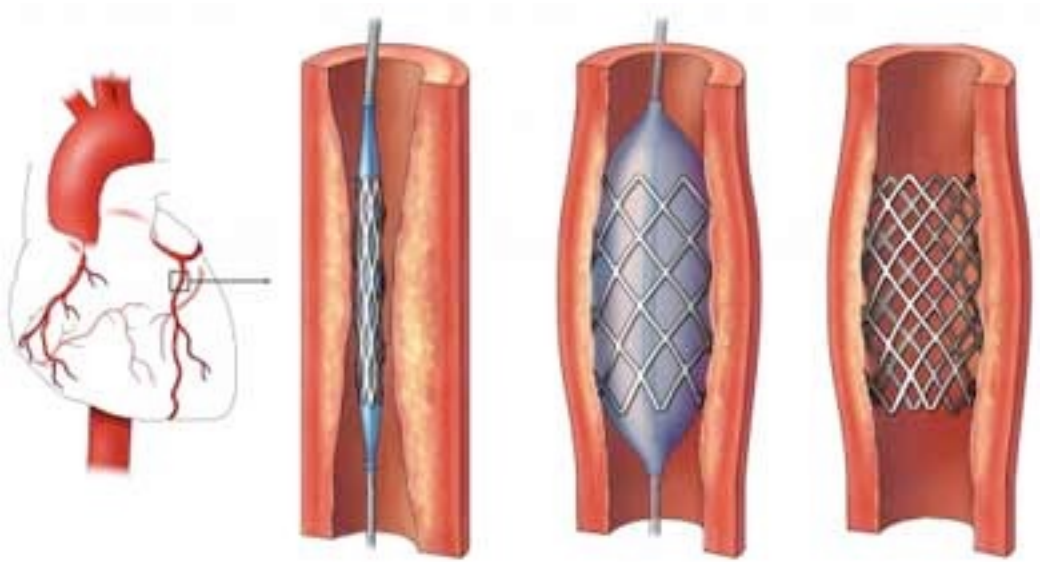


https://en.wikipedia.org/wiki/Electrocardiography#/media/File:Directions_of_EKG_leads.png



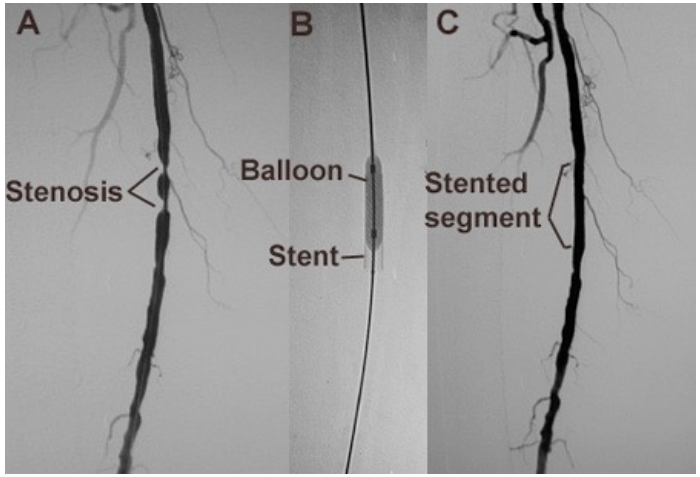
PCI

Insertion of coronary stent, catheterization through the femoral or radial artery. X-ray guided insertion of the balloon



http://www.beliefnet.com/healthandhealing/images/si55551520_ma.jpg

Harvard medical school

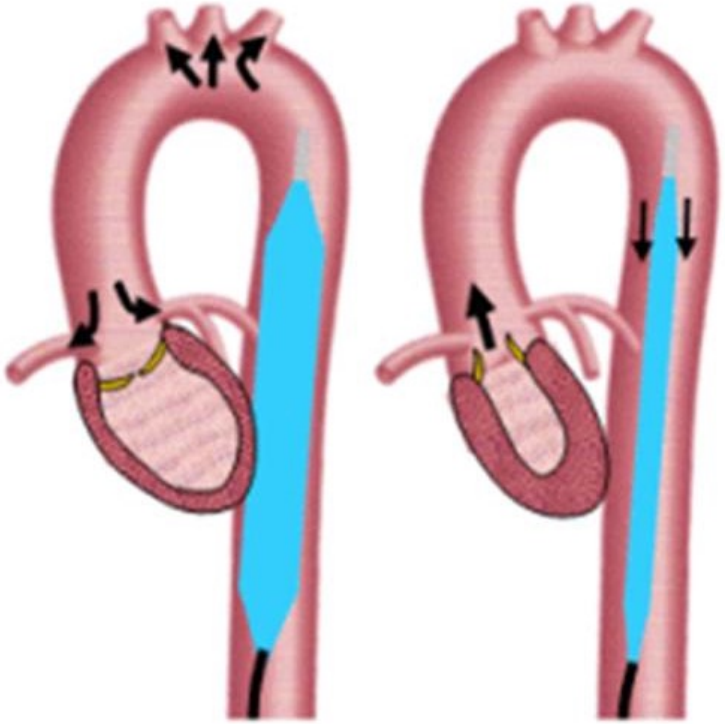


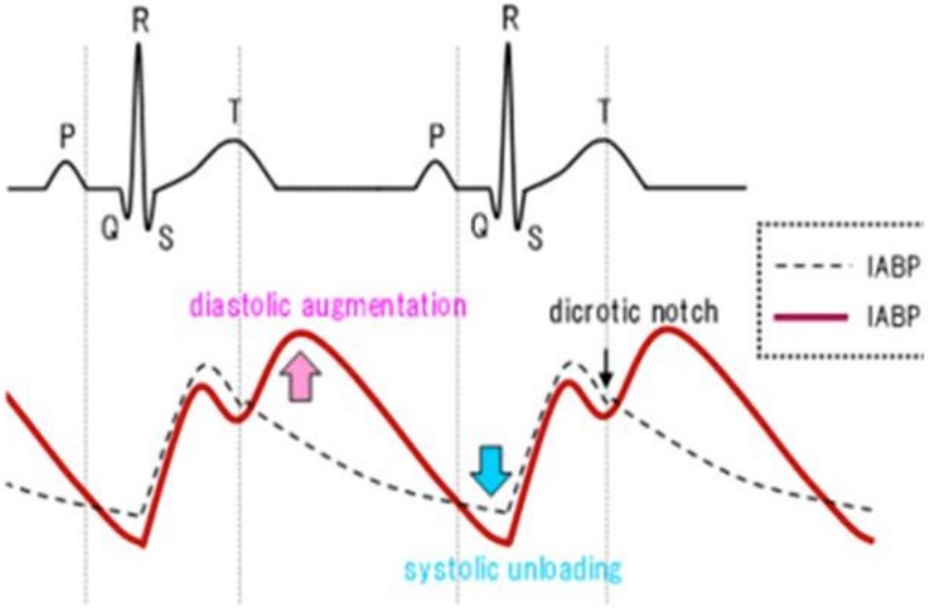
http://www.yoursurgery.com/procedures/angiography/images/FemAngioStent.jpg



IABP

- IABP, intra arterial balloon pump.



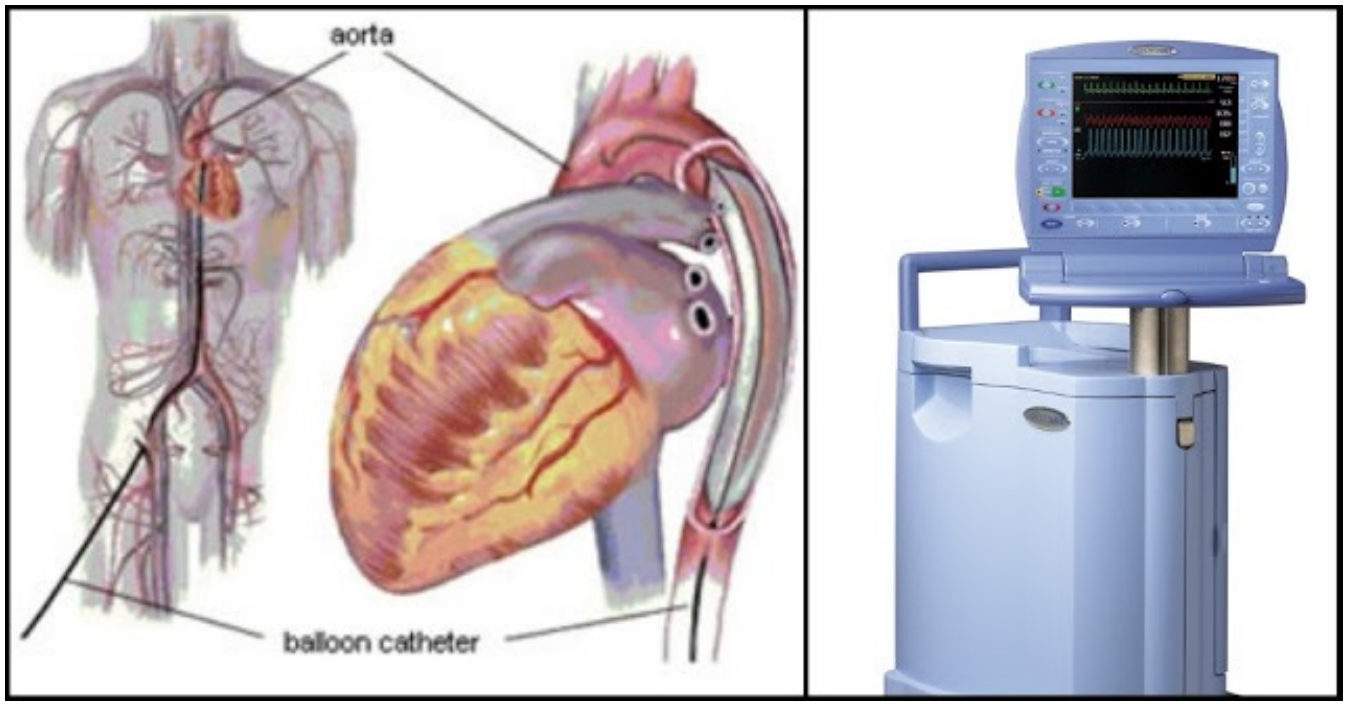


Picture courtesey: http://www.eonet.ne.jp/~hidarite/ce/sinpai06.html



IABP

- The main purposes of the IABP:
  - To increase cardiac output
  - To increase myocardial perfusion



http://3.bp.blogspot.com/-Kdkdk9AV2S8/TaMVi0DPsBI/AAAAAAAAAtk/Wde4h-s9mFo/s640/Picnik+collage+iabp.jpg

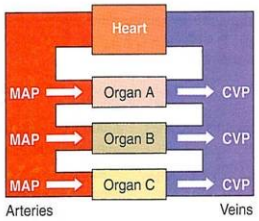
Cardiopulmonary bypass

What is necessary for a successful Cardiopulmonary Bypass? (CPB):

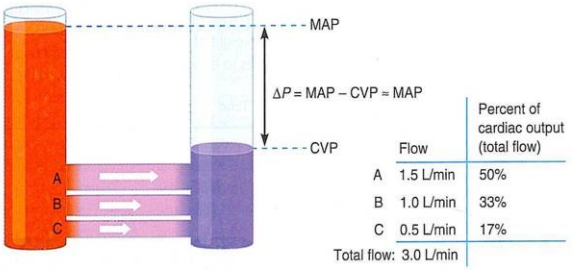
1. We need a basic understanding of the physiology of the circulation
2. A method to prevent blood from clotting
3. A blood pump for circulation
4. A way to exchange oxygen and carbon dioxide

http://3.bp.blogspot.com/-Kdkdk9AV2S8/TaMVi0DPsBI/AAAAAAAAAtk/Wde4h-s9mFo/s640/Picnik+collage+iabp.jpg

1. Basic physiology of circulation

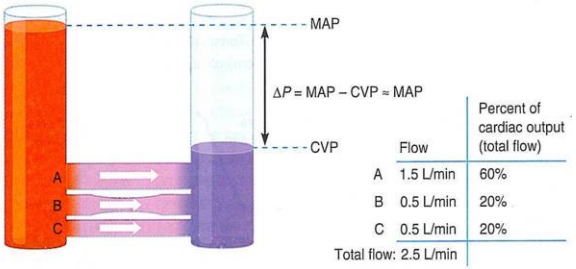


(a)



	Flow	Percent of cardiac output (total flow)
A	1.5 L/min	50%
B	1.0 L/min	33%
C	0.5 L/min	17%
Total flow:	3.0 L/min	

(b)



	Flow	Percent of cardiac output (total flow)
A	1.5 L/min	60%
B	0.5 L/min	20%
C	0.5 L/min	20%
Total flow:	2.5 L/min	

Germann WJ, Stanfield CL. Principles of Human Physiology, second edition.

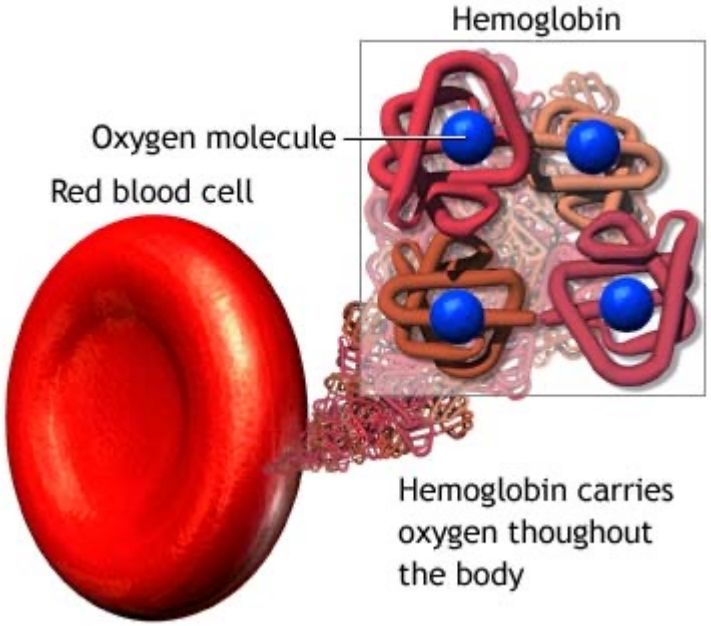
Poiseuille's law:

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

The effects of pressure gradients and resistance on blood flow.

Given a constant Mean Arterial Pressure (MAP) and Central Venous Pressure (CVP) an increase in resistance in one organ results in a reduction of total flow and a change in distribution of blood flow

1. Basic physiology of circulation



Germann J, Stanfild CL. Principles of Human Physiology, second edition.

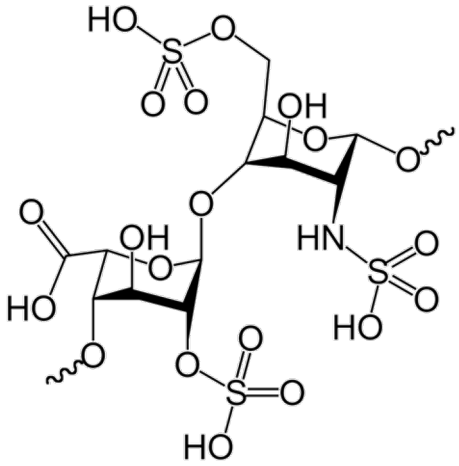
http://www.dhmc.org/shared/adam/graphics/images/en/19443.jpg

Transport-system with several purposes: Transport of oxygen and carbon dioxide, delivery of blood sugar and removal of waste, temperature regulation, providing mechanisms for stoppage of bleeding and being an active part of the immune system

2. Prevent blood from clotting



Jay McLean, the discoverer of Heparin



Heparin

http://www.oralchelation.net/heartdisease/ChapterEight/

When whole blood is exposed to nonendothelialized surfaces, blood clotting will occur. Some kind of anticoagulant was needed to avoid clotting in a heart-assisting device.

1916 – Jay McLean discovered a powerful anticoagulant, Heparin.

Activated clotting time (ACT)

ACT monitoring principle

- Add a solution that will trigger clotting
- Monitor the time until a certain amount of the blood is clotted
- Optical or mechanical readings of clotting



How can we design a system for monitoring this clotting?

Labcompare.com

Viscosimetric ACT

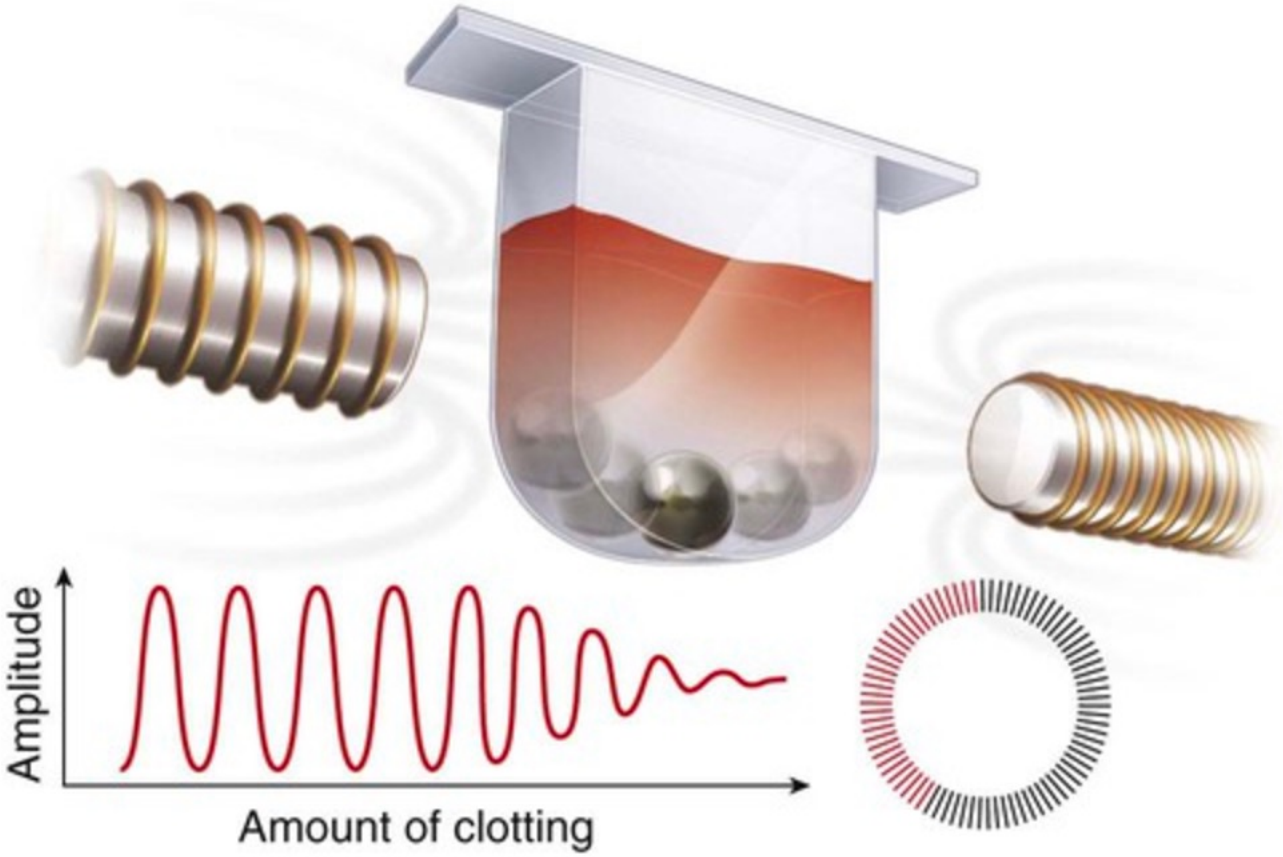


FIGURE 47-1 Viscosimetric (electromechanical) clot detection in a Diagnostica Stago analyzer. A steel ball oscillates in an arc from one side of the cuvette to the other. Movement is monitored continuously within a magnetic field. As the sample clots, viscosity rises and movement of the steel ball is impeded. Variation in amplitude stops the timer, and the interval is the clotting time.

https://clinicalgate.com/coagulation-instrumentation/

Photo-optical ACT

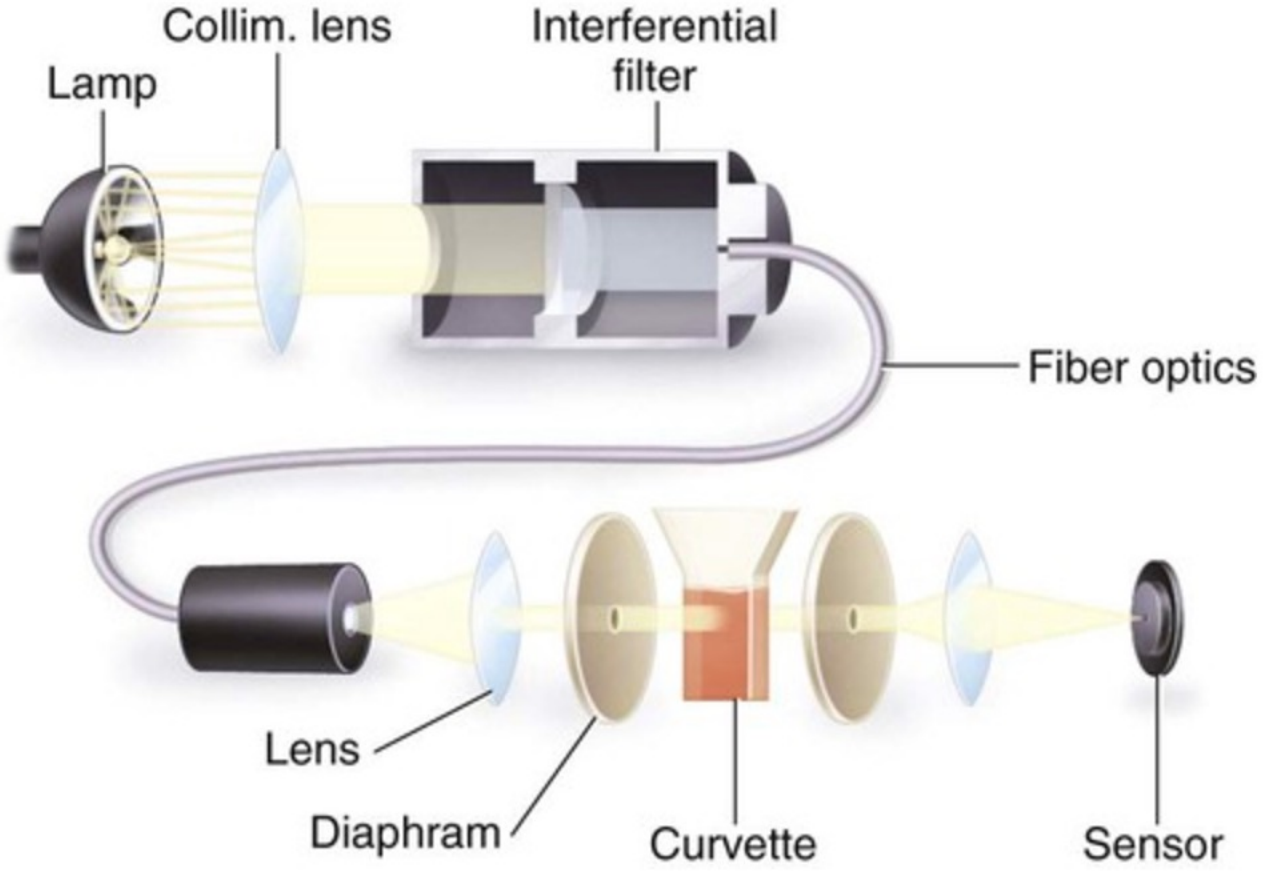


FIGURE 47-2 Photo-optical (turbidometric) clot detection. Polychromatic light is focused by a collimator and filtered to transmit a selected wavelength. Monochromatic light is transmitted by fiber optics and focused on the reaction cuvette. As fibrin forms, opacity increases and the intensity of light reaching the sensor decreases. *Collim.*, Collimator.

https://clinicalgate.com/coagulation-instrumentation/

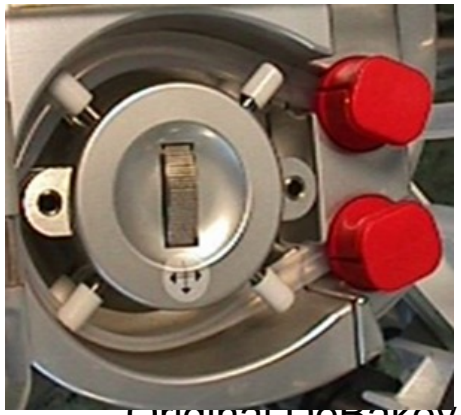


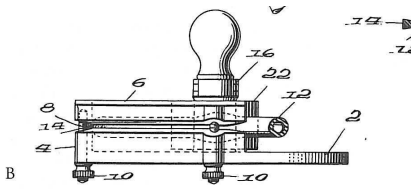
ACT

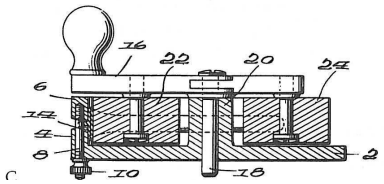
Sources of error?

1. Rotational speed
2. Blood viscosity
3. Magnet detector resolution
4. Tube properties (friction)
5. Other blood properties
6. ++

3. A blood pump







Original DeBakey roller pump. New Orleans Med Surg J 1934;87:387

1934 - DeBakey made a modification to the Porter-Bradley pump to prevent creepage of the latex rubber tubing (patent 2 018 998)

This is essentially the same roller pump that is used today.

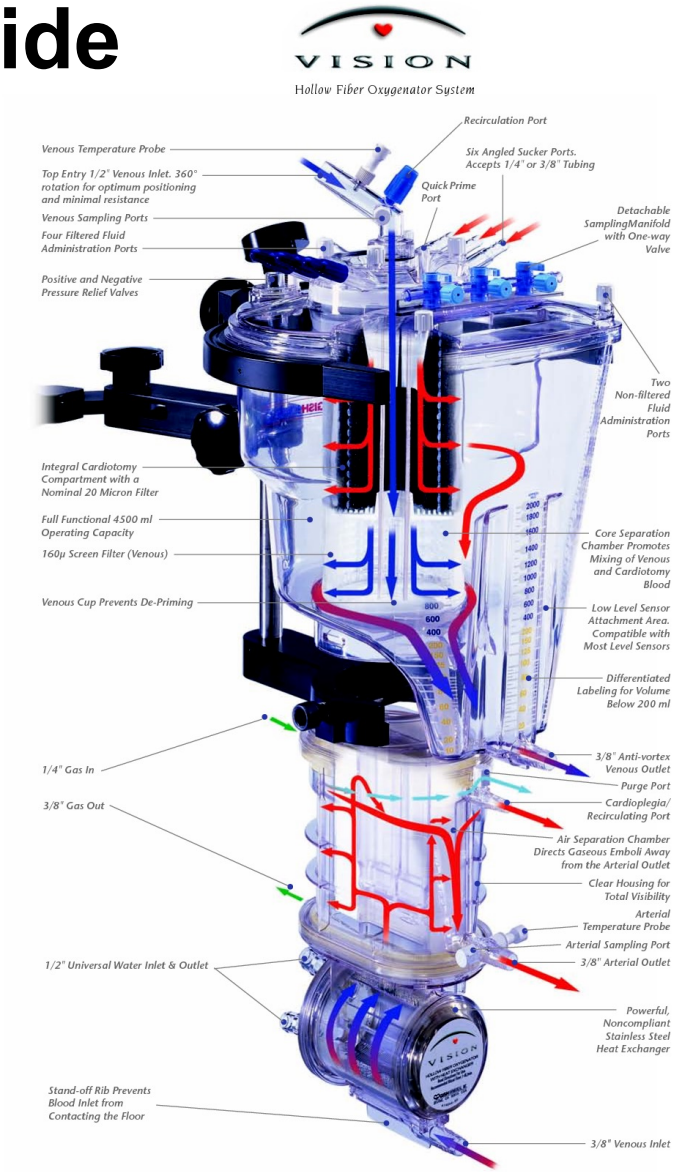


Centrifugal pump vs Roller pump

	Roller pump	Centrifugal pump
Advantages	Inexpensive, reusable	No disruption from excessive line pressure buildup
	Easy to sterilize	Decreased blood trauma
	Simple flow rate det.	No tubing wear
Disadvantages	Blood trauma	Needs flowmeter
	Circuit disruption	Retrograde flow possible when pump stops
	Occlusion variability affects flow rate	More expensive
	Tubing wear	

http://tele.med.ru/book/cardiac_anesthesia/text/gr/gr003.htm

4. A way to exchange oxygen and carbon dioxide



http://www.docstoc.com/docs/109449392/Hollow-Fiber-Oxygenator-System

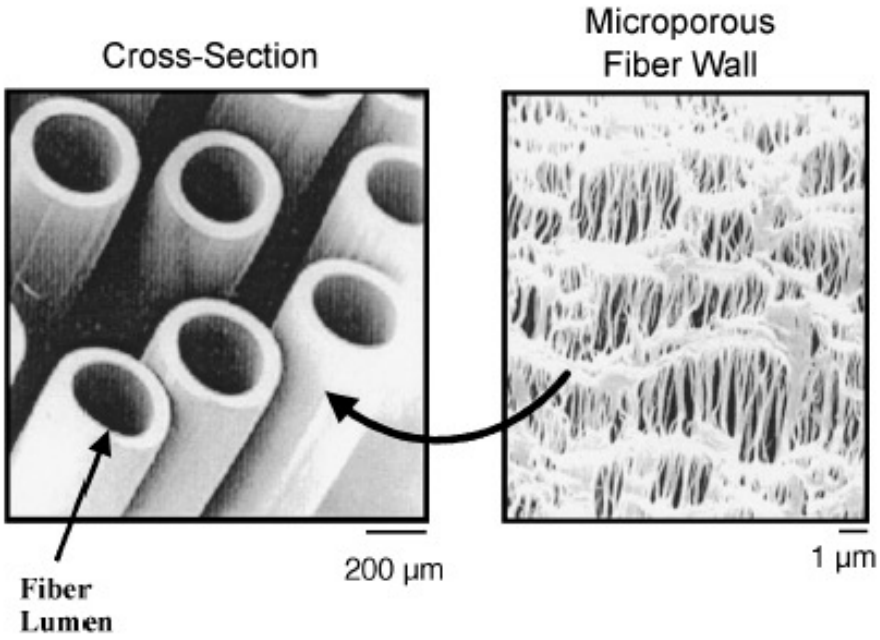
4. A way to exchange oxygen and carbon dioxide

Hollow fibre oxygenators

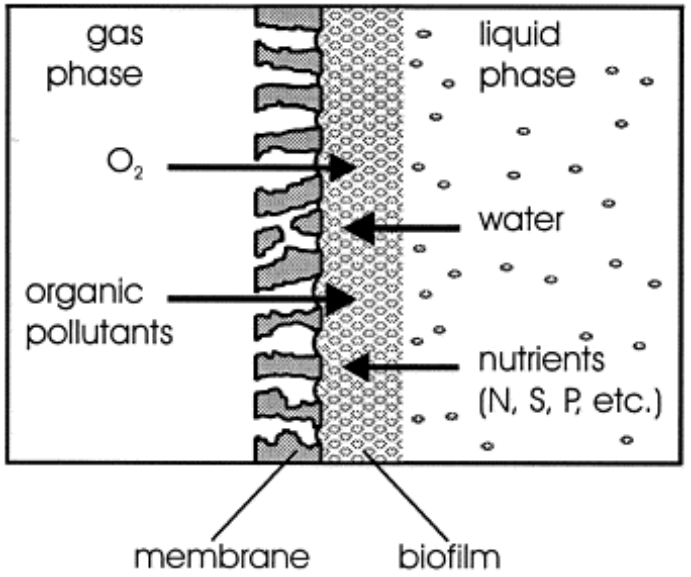
- Hydrophobic surface that allow diffusion of gases across the membrane. Due to concentration gradients, oxygen diffuses into the blood while carbon dioxide diffuses out of the blood
- Small polymer tubes, 20 to 50 um thick, with an outer diameter of approximately 200 to 400 um.
- Blood flows outside the fibres while air (sweep gas), flows inside
- Carbon dioxide is exited through the exhaust-port of the oxygenator

4. A way to exchange oxygen and carbon dioxide

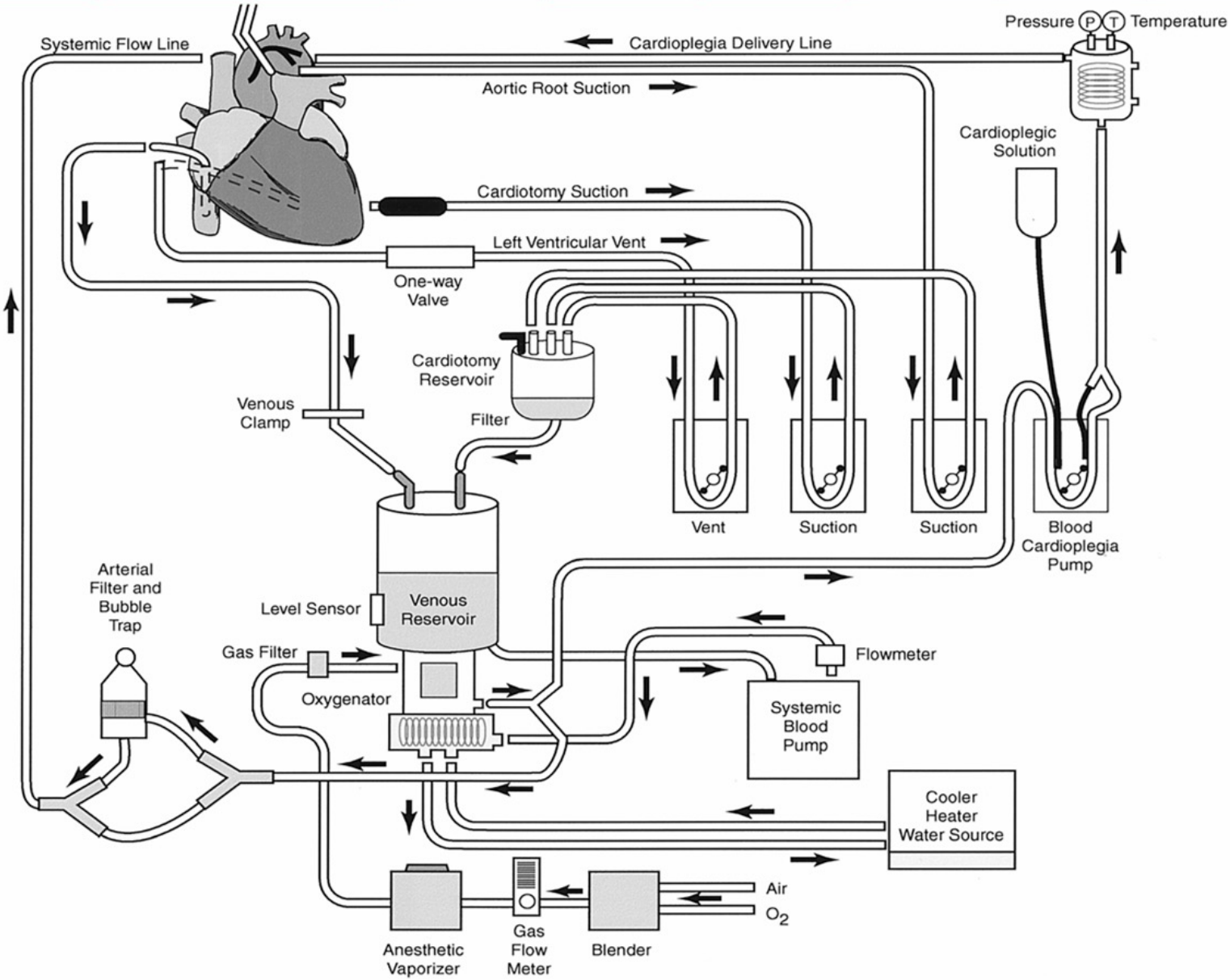
Hollow fiber oxygenators



portal.unimap.edu.my



http://ars.els-cdn.com/content/image/1-s2.0-S0168165697001697-gr1.gif


Systemic Flow Line
Cardioplegia Delivery Line
Pressure P T Temperature
Aortic Root Suction
Cardioplegic Solution
Cardiotomy Suction
Left Ventricular Vent
One-way Valve
Cardiotomy Reservoir
Venous Clamp
Filter
Vent
Suction
Suction
Blood Cardioplegia Pump
Arterial Filter and Bubble Trap
Level Sensor
Venous Reservoir
Gas Filter
Flowmeter
Oxygenator
Systemic Blood Pump
Cooler Heater Water Source
Air
O2
Anesthetic Vaporizer
Gas Flow Meter
Blender

Cannulation

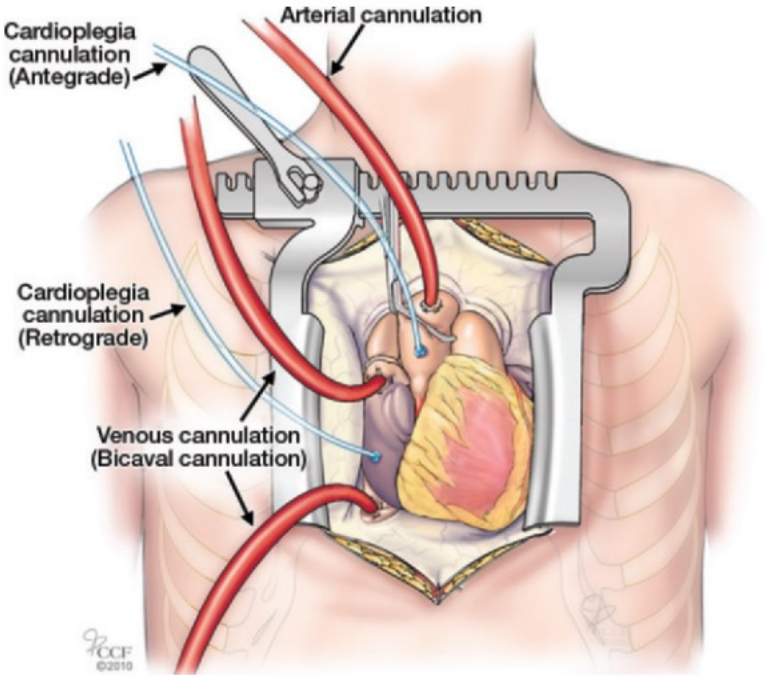
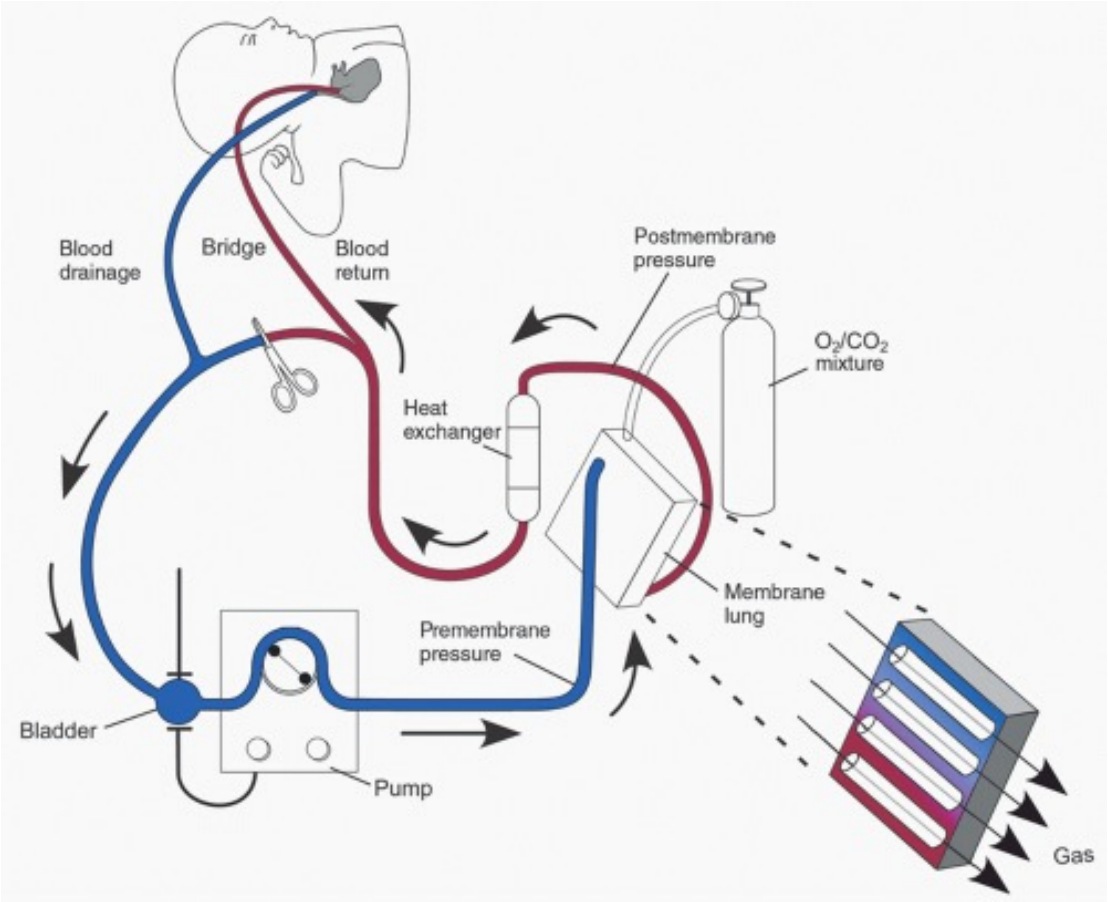


Figure 2. Drawing shows several routes of cannulation: arterial cannulation of the distal portion of the ascending aorta, antegrade cardioplegia cannulation, retrograde cardioplegia cannulation, and bicaval venous cannulation. *IVC* = cannula into inferior vena cava, *SVC* = cannula into superior vena cava. (Reprinted, with permission, from the Cleveland Clinic Center for Medical Art and Photography.)



ECMO (Extra corporal membrane oxygenation)



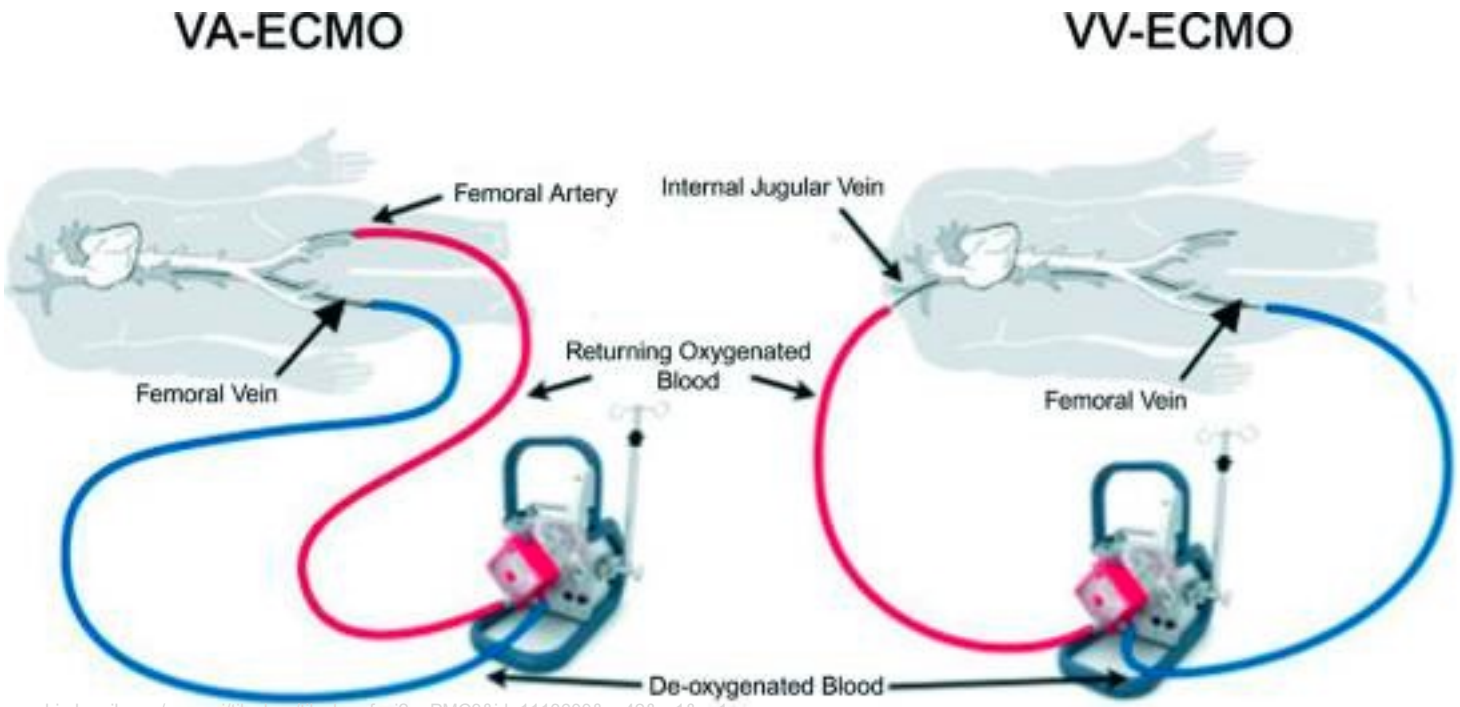
https://thoracickey.com/wp-content/uploads/2016/06/C31-FF1.gif

ECMO



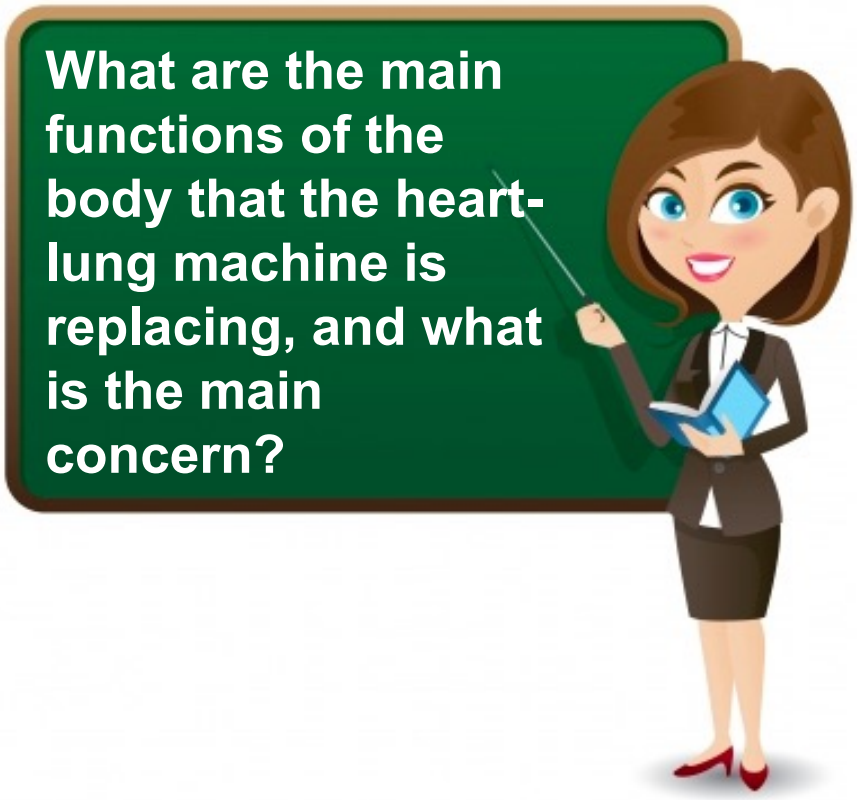
Differences between ECMO and CPB

a. Cannulation. ECMO is typically cannulated through the neck (cervical) under local anesthesia, CPB is connected to the aorta under full anesthesia
b. CPB is short-time, ECMO is typically 3-10 days
c. ECMO is meant for intrinsic recovery of heart and lungs, CPB is for bypass
d. ECMO can be veno-venous or veno-arterial
e. Centrifugal pump, less priming volume, blood trauma, platelet activation and inflammatory response.



https://www.ncbi.nlm.nih.gov/corecgi/tileshop/tileshop.fcgi?p=PMC3&id=1113600&s=42&r=1&c=1

Exercise examples







UiO : Department of Physics
University of Oslo

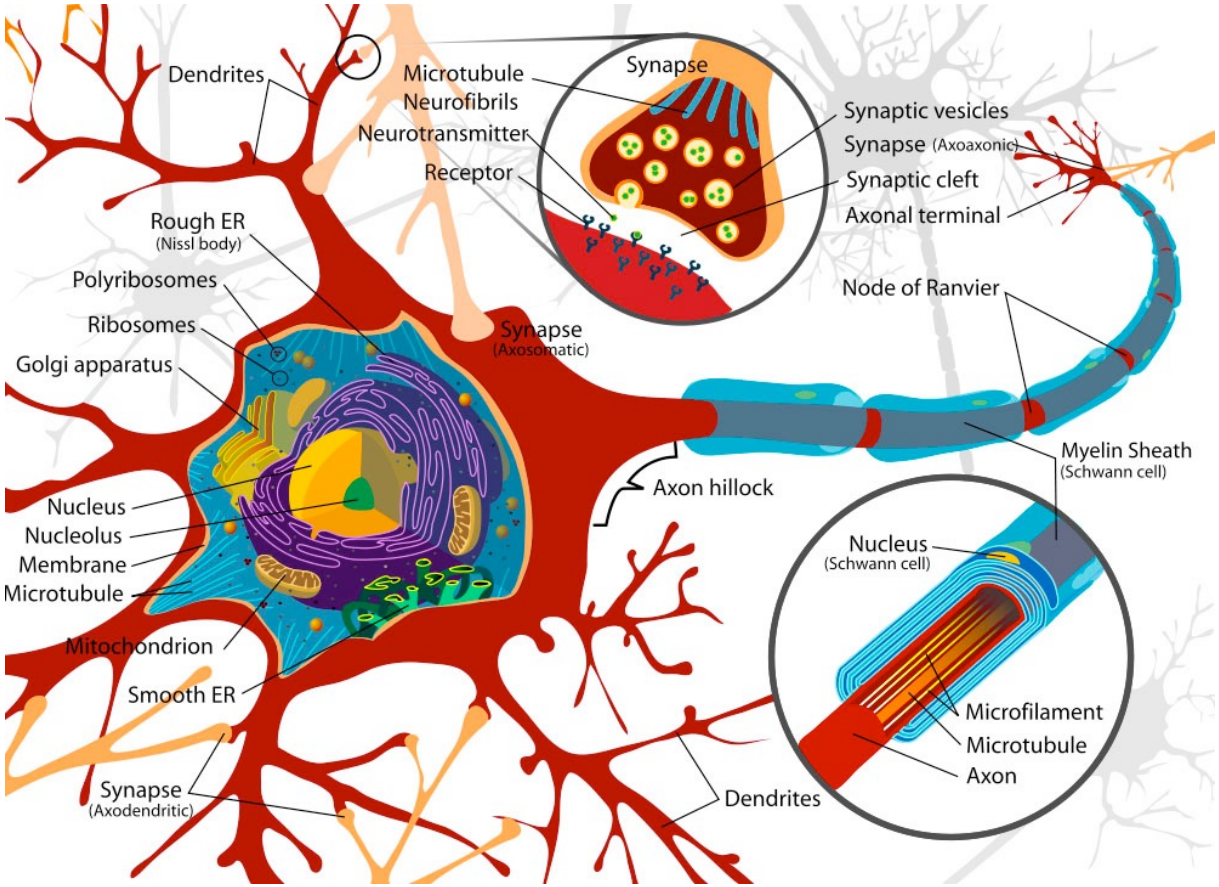
FYS 4250

Lecture 12

X-ray files: The truth is out there

Neuron (Nerve cell)

Dendrite recieve information
Axon send information



http://paleozonenutrition.com/wp-content/uploads/2012/02/nerve-cell.jpg

Neuron stimulate other neurons through synapses, depending on the stimulus and the neuron, graded potentials can cause hyperpolariation or depolarisation

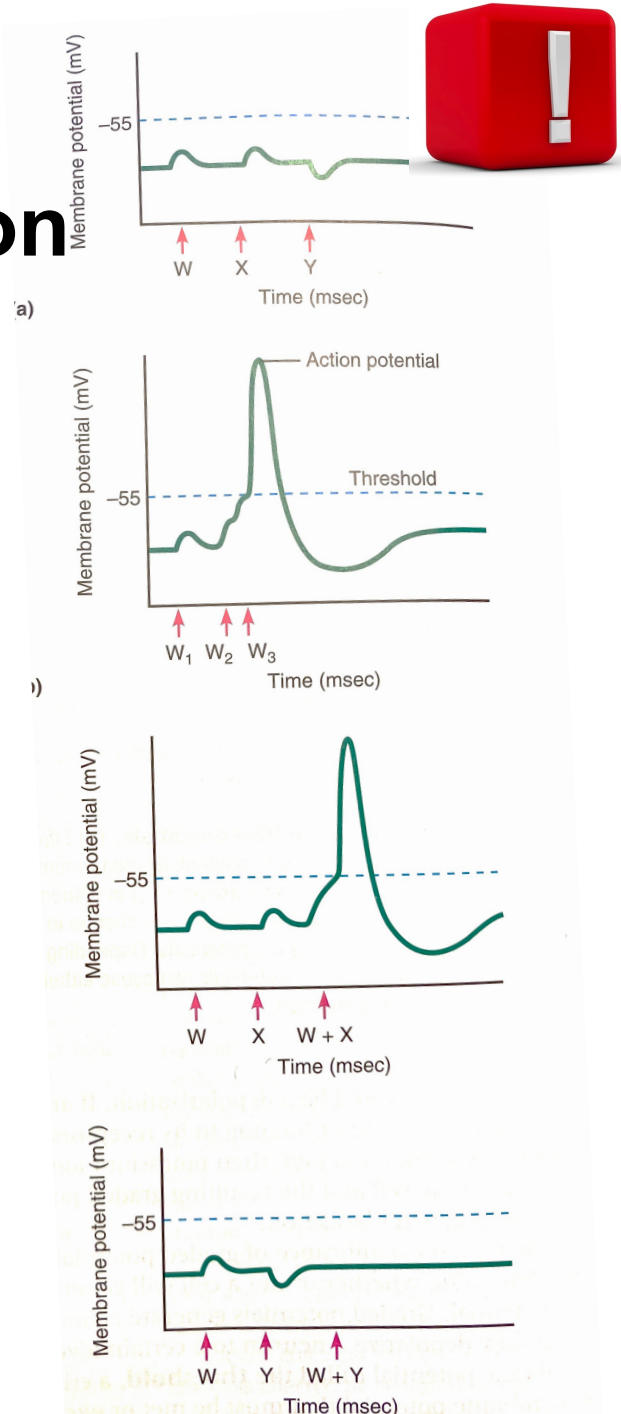
Temporal and spatial summation

Stimuli W, X and Y influence the membrane potential of a neuron. Stimuli W and X depolarize the cell while Y hyperpolarizes the cell (a).

b. Temporal summation of stimulus W results in depolarisation to above treshold -> generating action potential

c. Spatial summation of stimuli W and X resulting in depolarisation above treshold -> generating action potential

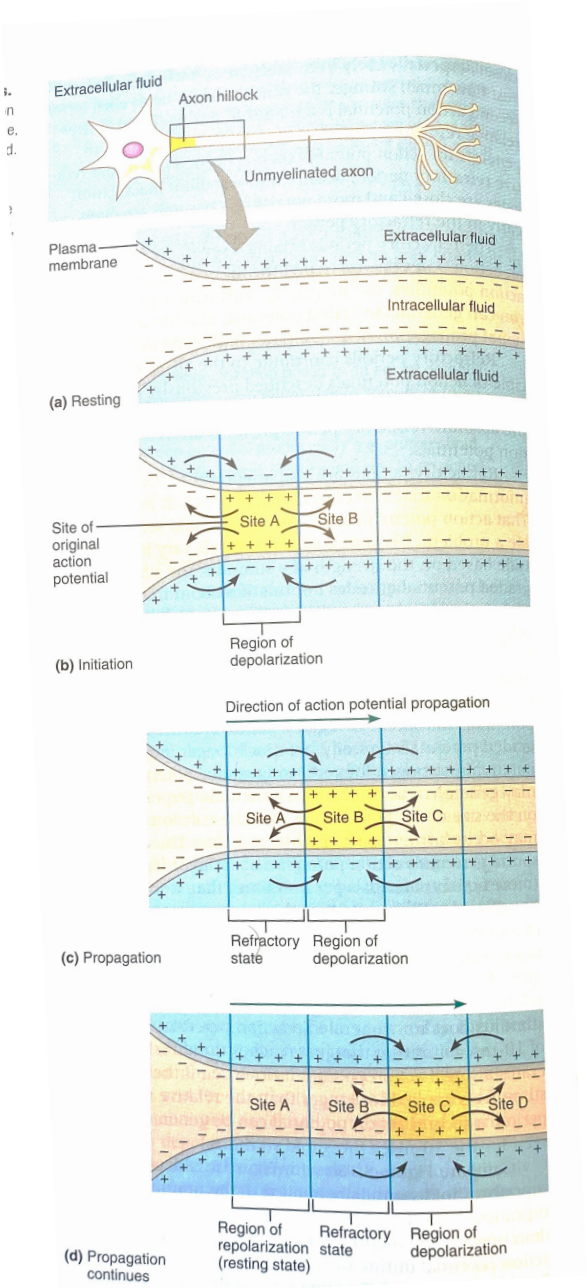
d. Spatial summation of stimuli W and Y resulting in no change in membrane and therefore no action potential



Source: Principles of human physiology, Germann and Stanfield

Propagation of action potentials in unmyelinated cells

a. Resting membrane potential
b. Initiation of conduction. An action potential occurs at site A on the membrane.The charge separation is a force for current to move. Local currents produced by ions moving are shown by arrows.
c. Propagation of conduction, current depolarizes the adjacent region of membrane to threshold, eliciting an action potential here
d. Continuation of propagation. Refrectory periods prevent action potentials from traveling in the reverse direction



Source: Principles of human physiology, Germann and Stanfield

Propagation of action potentials in myelinated cells

a. Resting membrane potential
b. Initiation of conduction. An action potential occurs at site A on the membrane.The charge separation is a force for current to move. Local currents produced by ions moving are shown by arrows.
c. Propagation of conduction, current depolarizes the adjacent region of membrane to threshold, eliciting an action potential here
d. Continuation of propagation. Refrectory periods prevent action potentials from traveling in the reverse direction

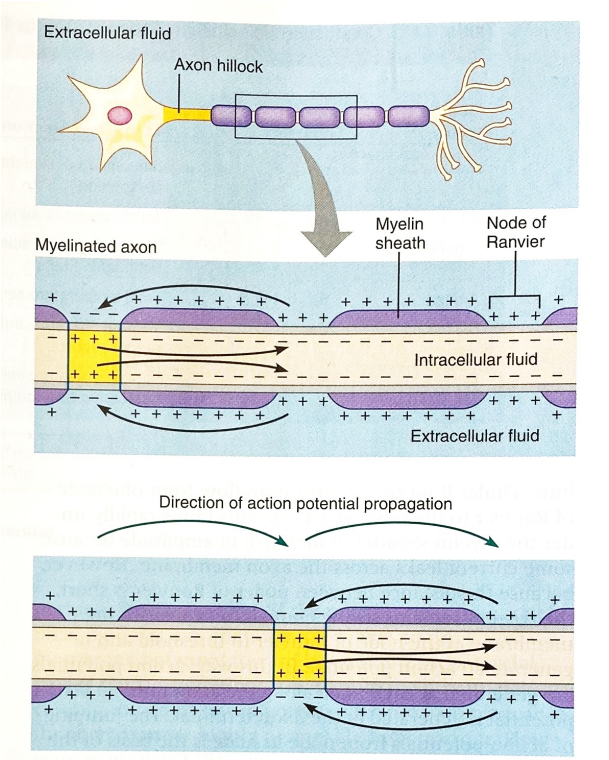
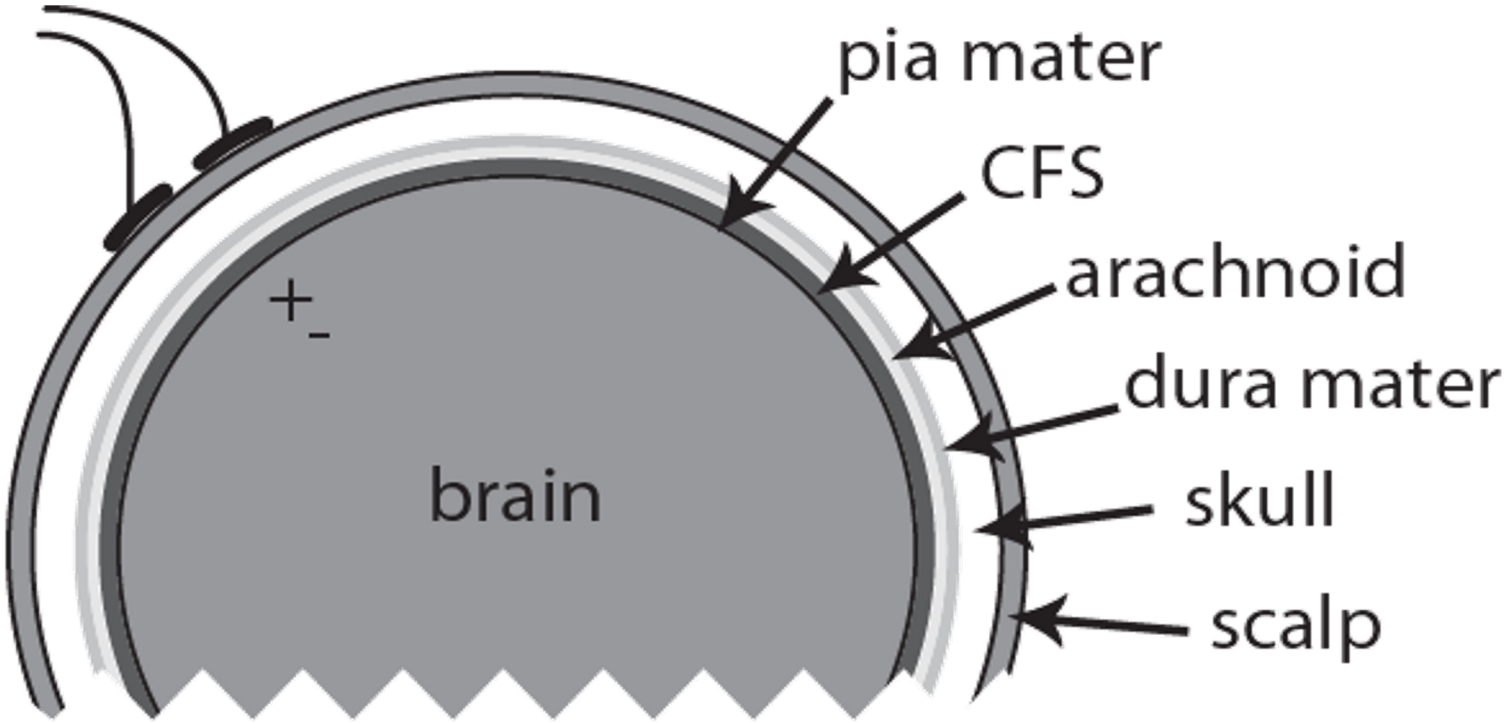


Figure 8.20 Saltatory conduction in myelinated axons. An action potential in a myelinated axon produces electrical gradients in the intracellular and extracellular fluids that are similar to those observed in unmyelinated axons (see Figure 8.19). However, because very little current flows across the membrane where myelin insulates it, the current must flow all the way to the next node of Ranvier, where it depolarizes this area of the membrane to threshold and initiates an action potential.

Source: Principles of human physiology, Germann and Stanfield

Transmisjon through the scull



Source: Bioimpedance Bioelectricity Basics



EEG measurement

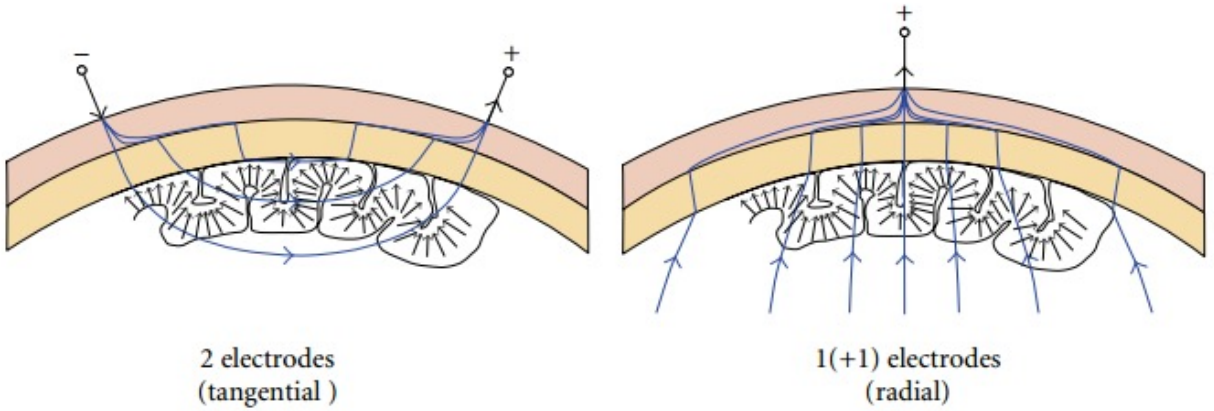


FIGURE 2: The Sensitivity Distributions of EEG. (Left) An EEG setup measuring the tangential components of neuroelectrical activity, where each bipolar lead is located relatively close to each other. (Right) An EEG setup measuring the radial components of neuroelectric activity, where the measuring electrode is located far from the reference electrode. The arrows in both figures represent macrocolumns of cellular architecture not dipolar sources.

The direction of the current is depending on the positioning of the electrodes, and the direction of the current decides the influence of the volume conductor with surrounding tissue

1. Katrina Wendel, Outi Väisänen, Jaakko Malmivuo, et al., “EEG/MEG Source Imaging: Methods, Challenges, and Open Issues,” Computational Intelligence and Neuroscience, vol. 2009, Article ID 656092, 12 pages, 2009. doi:10.1155/2009/656092

Source: Christian Tronstad

Biopotentail amplifiers

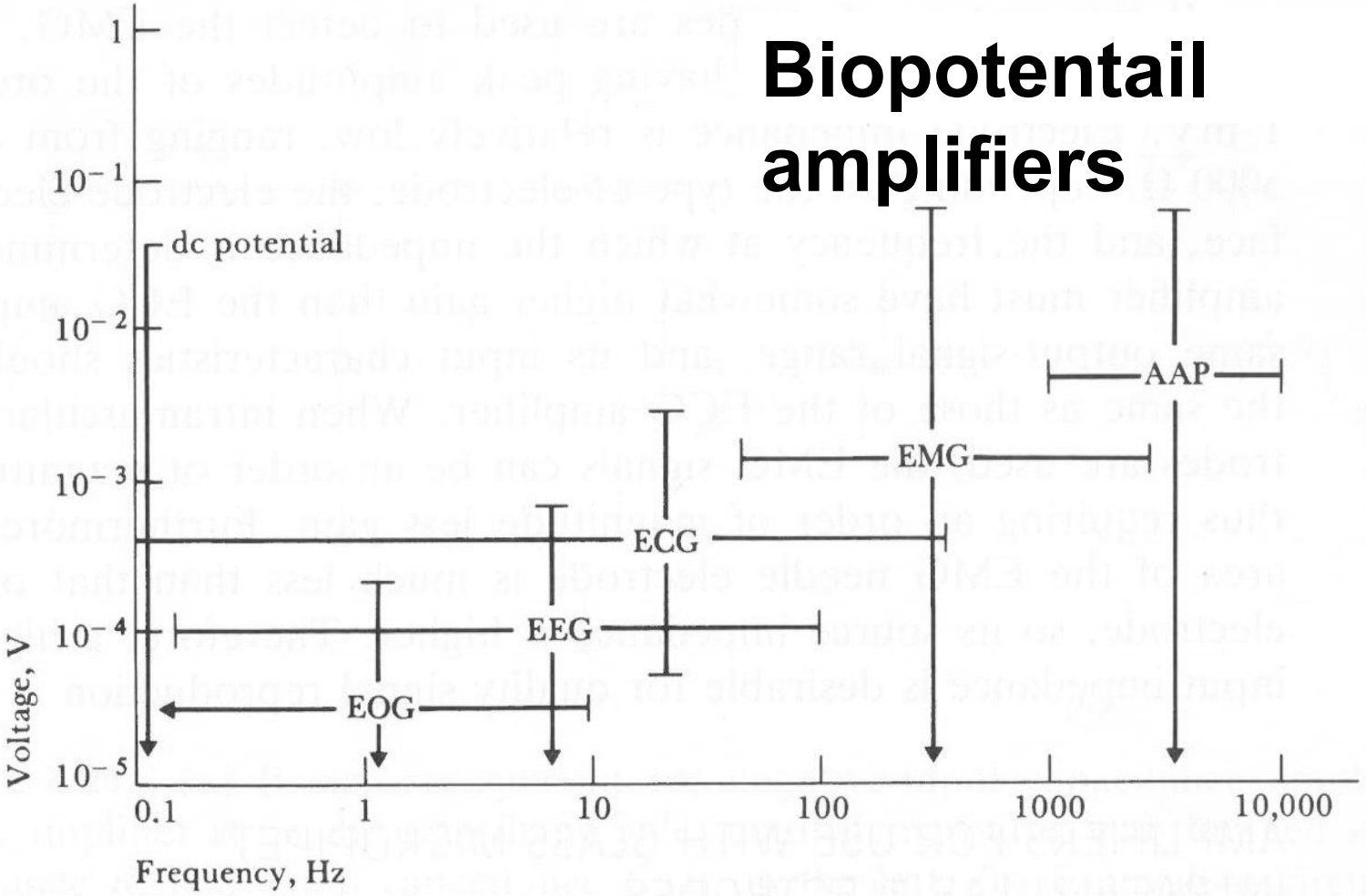
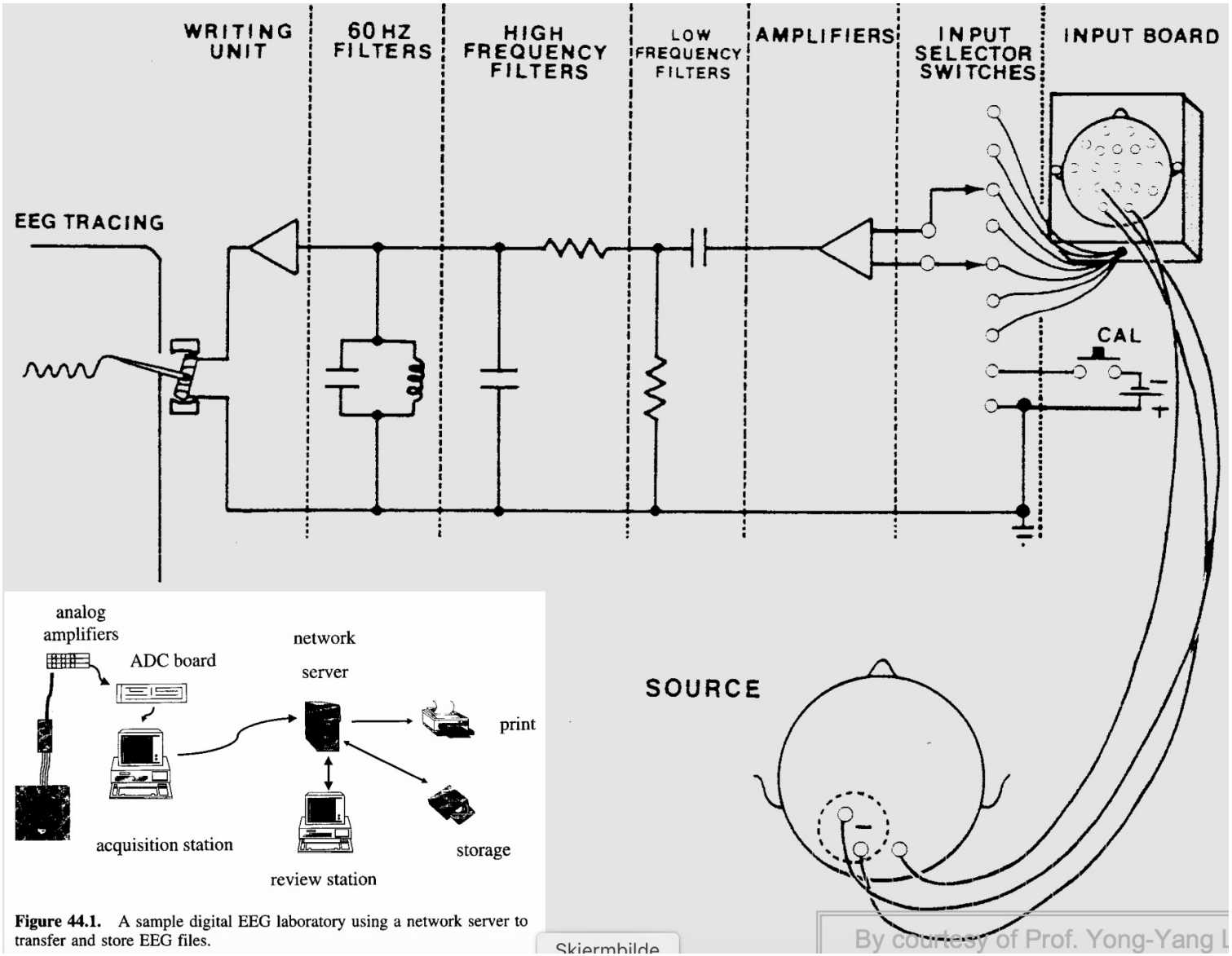


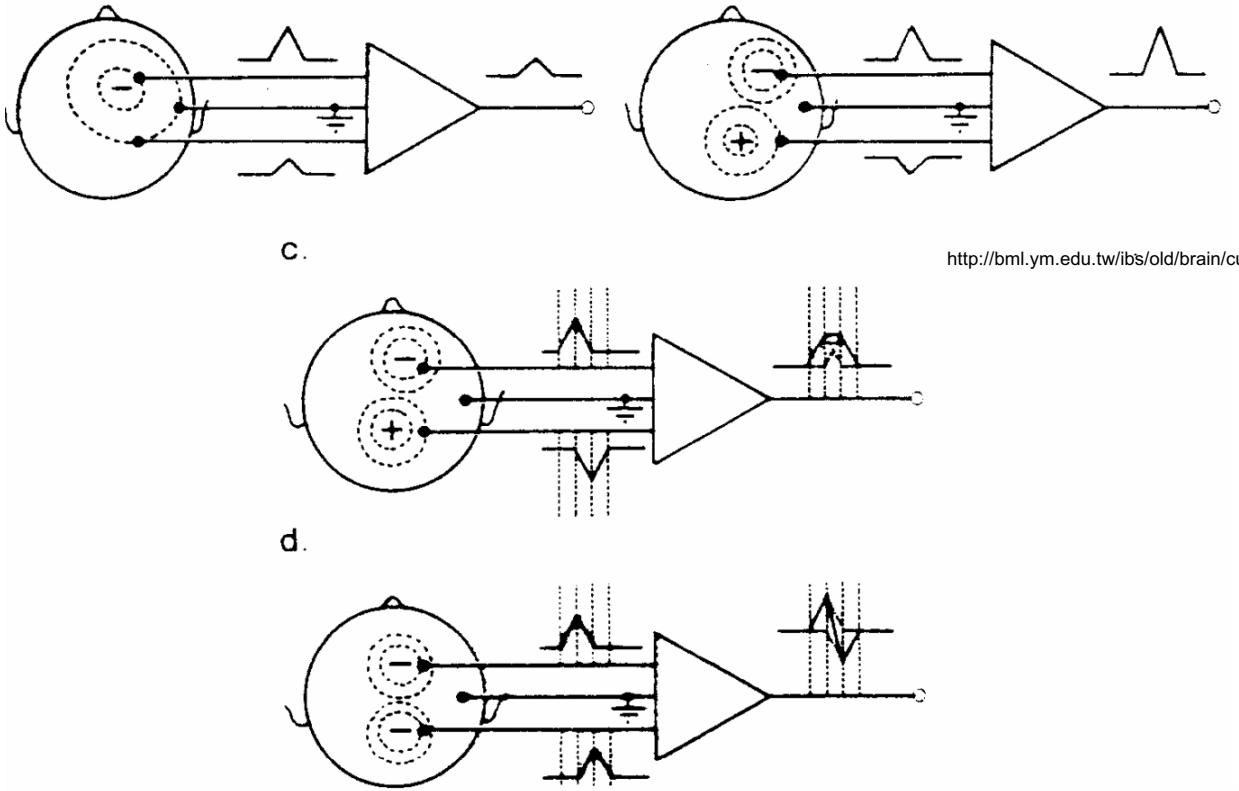
Figure 6.20 Voltage and frequency ranges of some common biopotential signals; dc potentials include intracellular voltages as well as voltages measured from several points on the body. EOG is the electrooculogram, EEG is the electroencephalogram, ECG is the electrocardiogram, EMG is the electromyogram, and AAP is the axon action potential. (From J.M.R. Delgado, "Electrodes for Extracellular Recording and Stimulation," in *Physical Techniques in Biological Research*, edited by W.L. Nastuk, New York: Academic Press, 1964.

EEG-amplification



http://bml.ym.edu.tw/ibs/old/brain/curricurium/952curricurium/file/MEG_EEG_Clinical%20applications.pdf

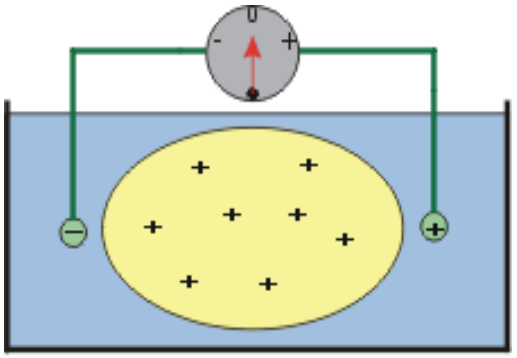
Differential amplification of signals

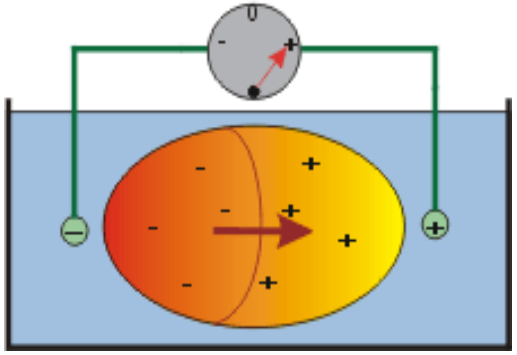


http://bml.ym.edu.tw/ibs/old/brain/curricurium/952curricurium/file/MEG_EEG_Clinical%20applications.pdf

Fig. 3.1. Differential amplification of simple signals, applied to input 1 (top input at the triangular amplifier symbol) and input 2 (bottom input) with respect to an electrical zero level at the ground connection (middle input). Electrical changes at scalp electrodes are indicated by fields on the head diagram; a change towards negative in an electrode is indicated by an upward deflection of the signal above or below the electrode lead; a change towards positive is indicated by a downward deflection. The same polarity convention is used for the signals at the amplifier output which represent pen deflections. – a. A negative signal at input 1 causes an upgoing pen deflection; – b. A positive signal at input 2 is inverted at the ground level and also causes an upgoing pen deflection; – c. Two signals of equal size but opposite polarity appearing simultaneously at both inputs are added to each other and cause a pen deflection twice the size of that caused by each potential alone; – d. Two signals of equal size and the same polarity applied simultaneously to both inputs are subtracted from each other and cause no pen deflection.

The volume conductor





A single active cell is immersed in a volume conductor (= body fluids, filled with ions). This is a problem of two parts:

1. The bioelectric source
2. The bathing medium or electrical load

1. The bioelectric source = active cell bathed by a volume conductor.

2. The magnitude of the field potential in a large bathing medium falls off exponentialley with increasing radial distance from the active fiber

Changes in the properties (eg. Resistivity) of the volume conductor can impact on the field potential magnitude

https://www.cvphysiology.com/Arrhythmias/A014

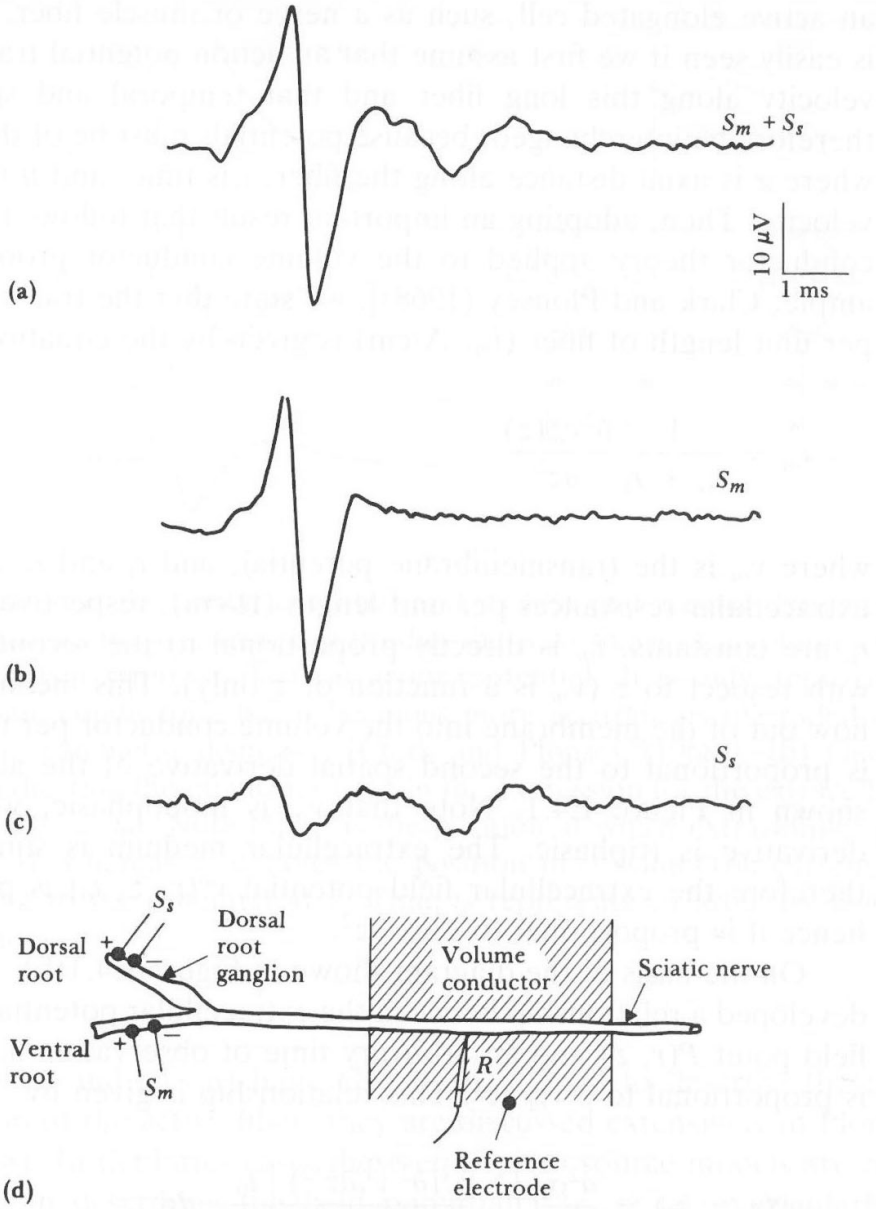
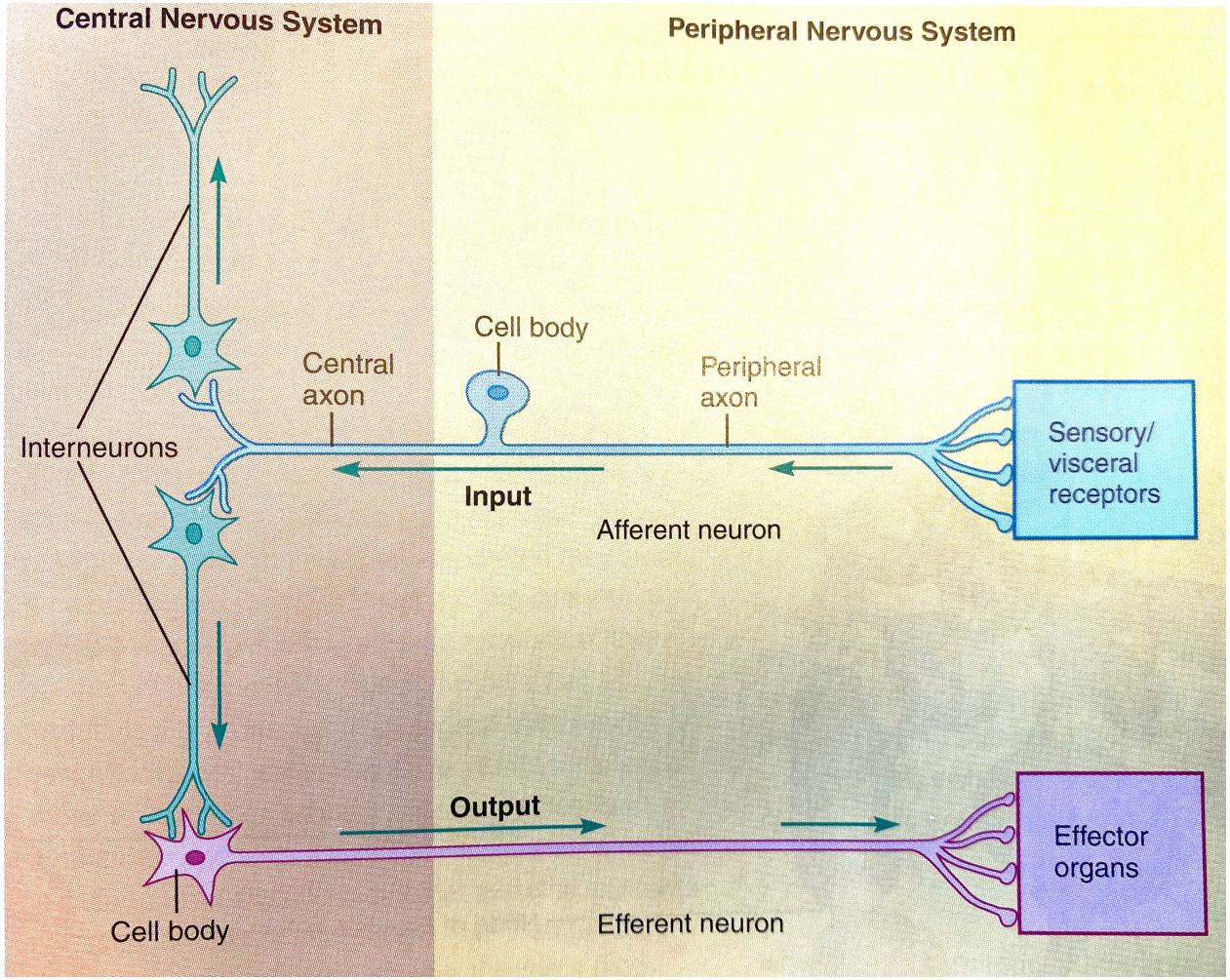


Figure 4.5 Extracellular field potentials (average of 128 responses) were recorded at the surface of an active (1-mm-diameter) frog sciatic nerve in an extensive volume conductor. The potential was recorded with (a) both motor and sensory components excited ($S_m + S_s$), (b) only motor nerve components excited (S_m), and (c) only sensory nerve components excited (S_s).

Summing up in the nerve-cell

Both motorical and sensorical fibers are excited simultaneously by electrical stimulus.
Dorsal root is sensoric
Ventral root is motoric, dorsal root is nervous
Stimulation of the many large diametric motoric fibers will give the largest extracellular response.
Stimulation of sensoric fibers will excite two groups of sensoric fibres.

The extracellular potential diminishes in amplitude and high-frequency contents as field point is moved to larger radial distances from the surface of the trunk



Functional classes of neurons, afferent neurons gather data while efferent neurons output data, note the different location of the cell body depending on the type.

Source: Principles of human physiology, Germann and Stanfield

Neural velocity

Nerve stimulation at two different sites, subtraction of the shorter latency from the longer latency gives conduction time

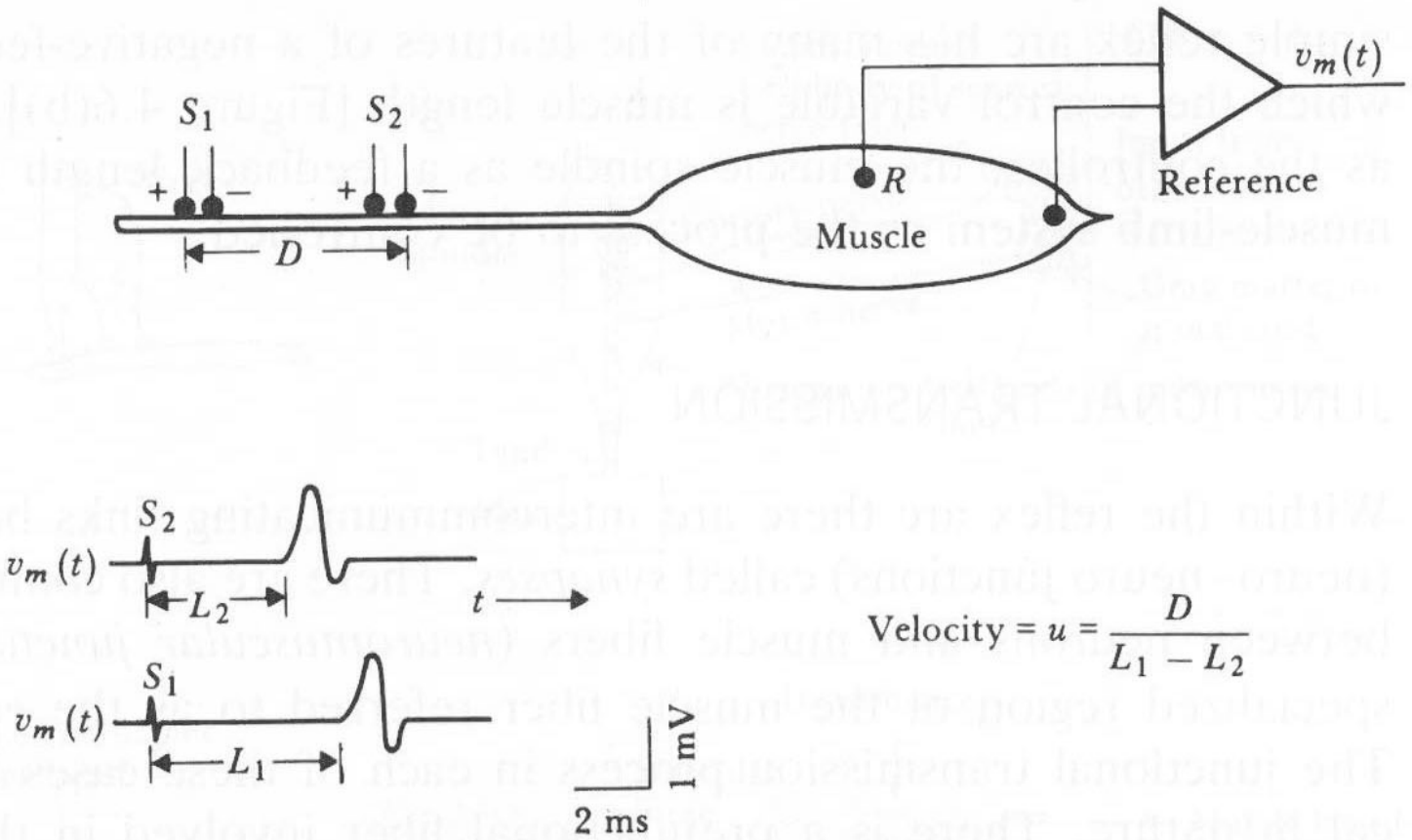


Figure 4.7 Measurement of neural conduction velocity via measurement of latency of evoked electrical response in muscle. The nerve was stimulated at two different sites a known distance D apart.

Neurography



Amp:
High gain
High input imp
Good CMRR
Low amp noise

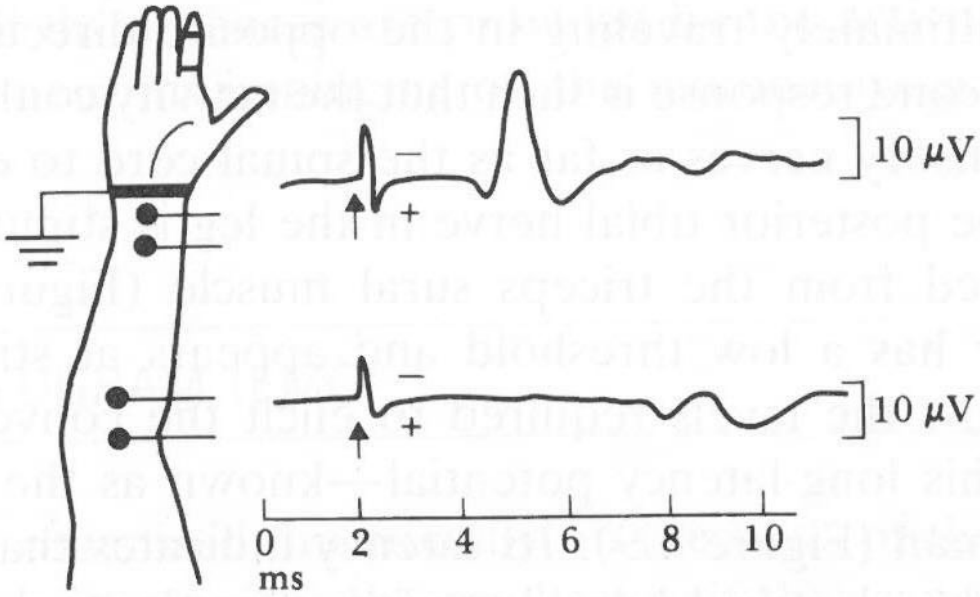


Figure 4.8 Sensory nerve action potentials evoked from median nerve of a healthy subject at elbow and wrist after stimulation of index finger with ring electrodes. The potential at the wrist is triphasic and of much larger magnitude than the delayed potential recorded at the elbow. Considering the median nerve to be of the same size and shape at the elbow as at the wrist, we find that the difference in magnitude and waveshape of the potentials is due to the size of the volume conductor at each location and the radial distance of the measurement point from the neural source. (From J. A. R. Lenman and A. E. Ritchie,

H-reflex

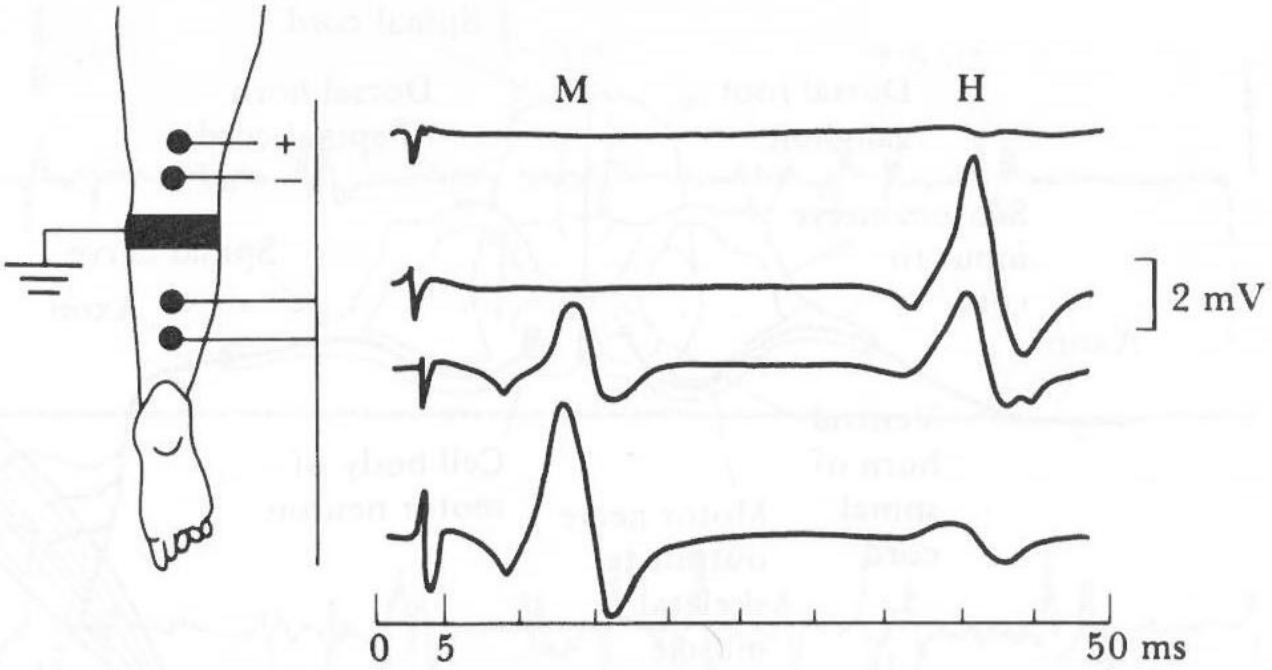


Figure 4.9 The H reflex The four traces show potentials evoked by stimulation of the medial popliteal nerve with pulses of increasing magnitude (the stimulus artifact increases with stimulus magnitude). The later potential or H wave is a low-threshold response, maximally evoked by a stimulus too weak to evoke the muscular response (M wave). As the M wave increases in magnitude, the H wave diminishes. (From J. A. R. Lenman and A. E. Ritchie, *Clinical Electromyography*, 2nd ed., Philadelphia: Lippincott, 1977; reproduced by permission of the authors.)

Magnetoencefalography (MEG)

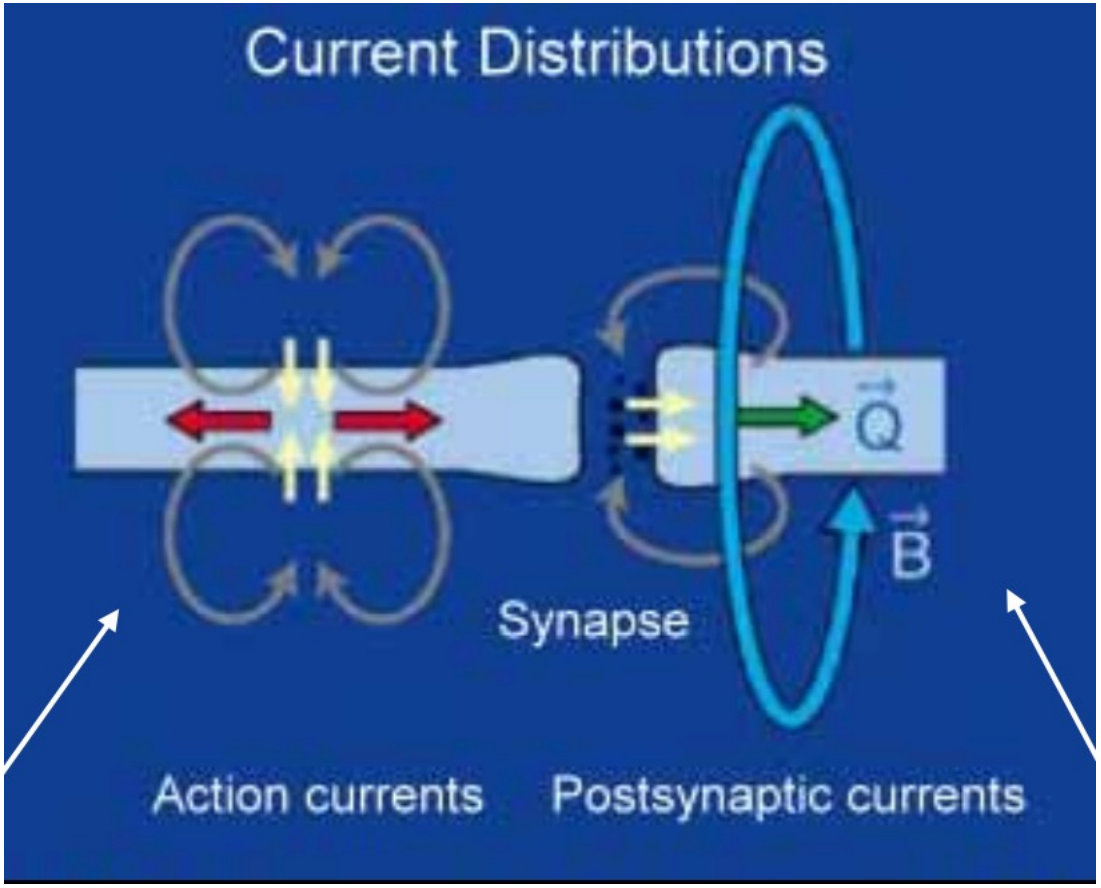


http://conic.ntu.edu.sg/Facilities/Magnetoencephalography_MEG/PublishingImages/10.png



Origin of the MEG-signal

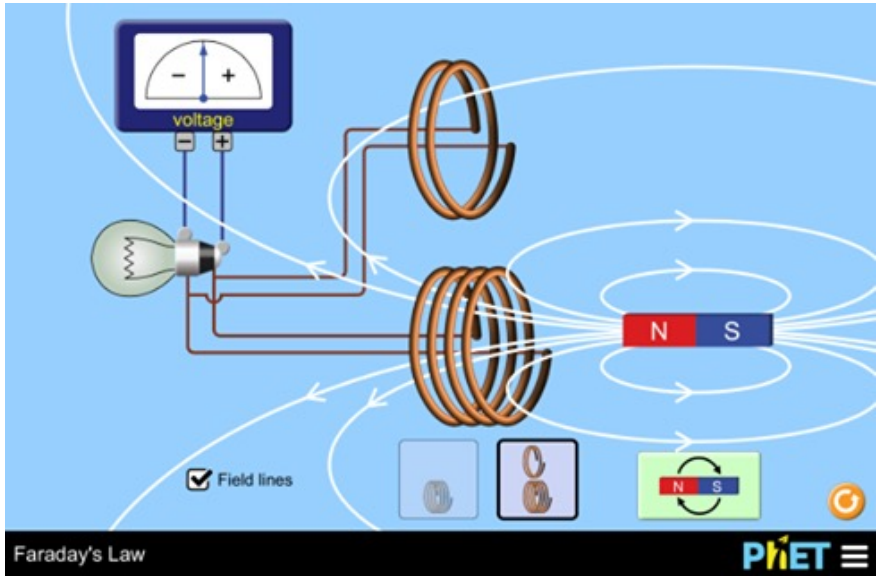
Because he current is bidirectional in the axon, the two dipoles will cancel each other



Because he current is unidirectional in the postsynapse, there will be a magnetic field

http://bml.ym.edu.tw/ibs/old/brain/curricurium/952curricurium/file/MEG_EEG_Clinical%20applications.pdf

Faradays law of induction



Source: Electronicslovers.com

Faraday's Law of Induction

The magnitude of the emf induced in a conducting loop is equal to the rate at which the magnetic flux through that loop changes with time.

$$\mathcal{E} = -\frac{d\Phi_B}{dt} \text{ (Faraday's law)}$$

If we change the magnetic flux through a coil of N turns, an induced emf appears in every turn and the total emf induced in the coil is the sum of these individual induced emfs.

$$\mathcal{E} = -N\frac{d\Phi_B}{dt} \quad (\text{coil of } N \text{ turns}) .$$

https://i.stack.imgur.com/ZCMN1.jpg

Magnetoencefalography (MEG)

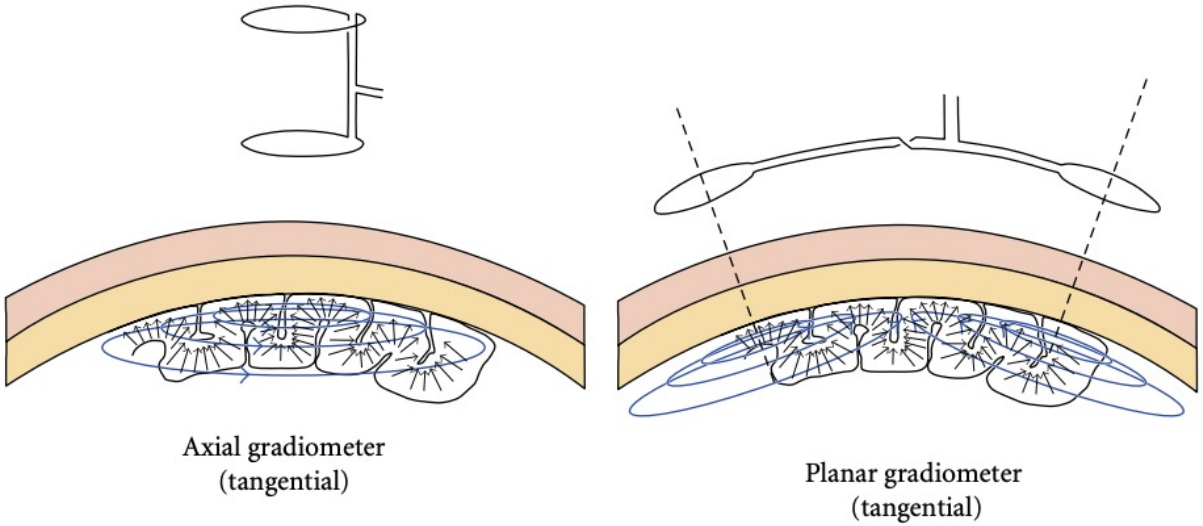


FIGURE 3: The Sensitivity Distributions of MEG. (Left) An MEG setup measuring the tangential components of neuroelectrical activity, using an axial gradiometer. (Right) An MEG setup measuring the tangential components of neuroelectric activity, using a planar gradiometer. The arrows in both figures represent macrocolumns of cellular architecture not dipolar sources.

Wendel: EEG/MEG Source Imaging: Methods, Challenges, and Open Issues



Advantages of MEG compared to fMRI and EEG

- MEG alone provides both timing as well as spatial information of the brain activity
- fMRI reflects brain activity (by measuring oxygenation of blood near the neuronss), while MEG measures directly neural activity
- MEG can be used on sleeping subjects
- No movement artefacts
- Sub-millisecond presicion, fMRI provides poor temporal information

http://ilabs.washington.edu/what-magnetoencephalography-meg

ERG

Electroretinogram

Eye 24 mm in diameter. Light transmitting parts -> cornea, anterior chamber, lens and vitreous chamber

A transparent fluid is found in the anterior chamber, vitreous chamber is filled with a transparent gel

Normal pressure 20 – 25 mmHg, necessary for a clear visual image

Glaucoma = high pressure condition, injure the retina. Caused by obstruction of flow between blood and fluid

5 types of nerve cells:

Photoreceptors, bipolar, horizontal, amacrine and ganglion cells (axons)

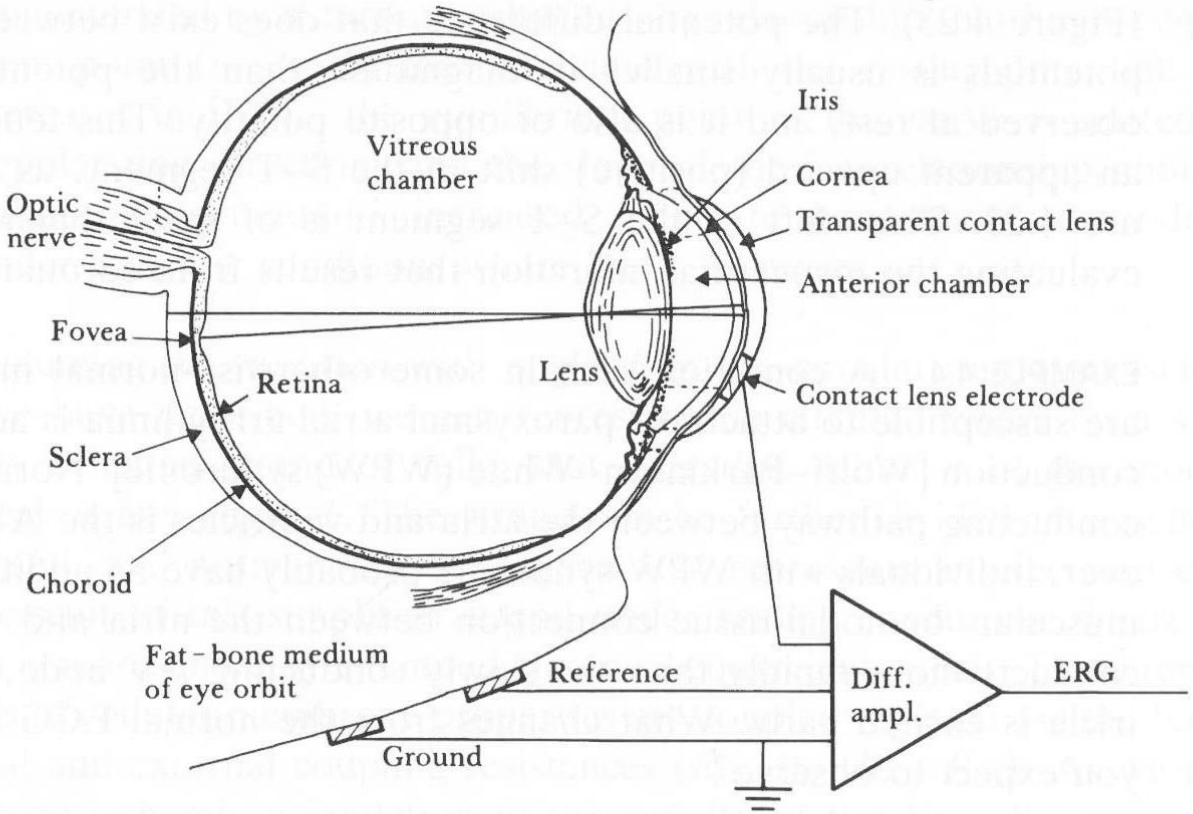


Figure 4.25 The transparent contact lens contains one electrode, shown here on horizontal section of the right eye. Reference electrode is placed on the right temple.

ERG

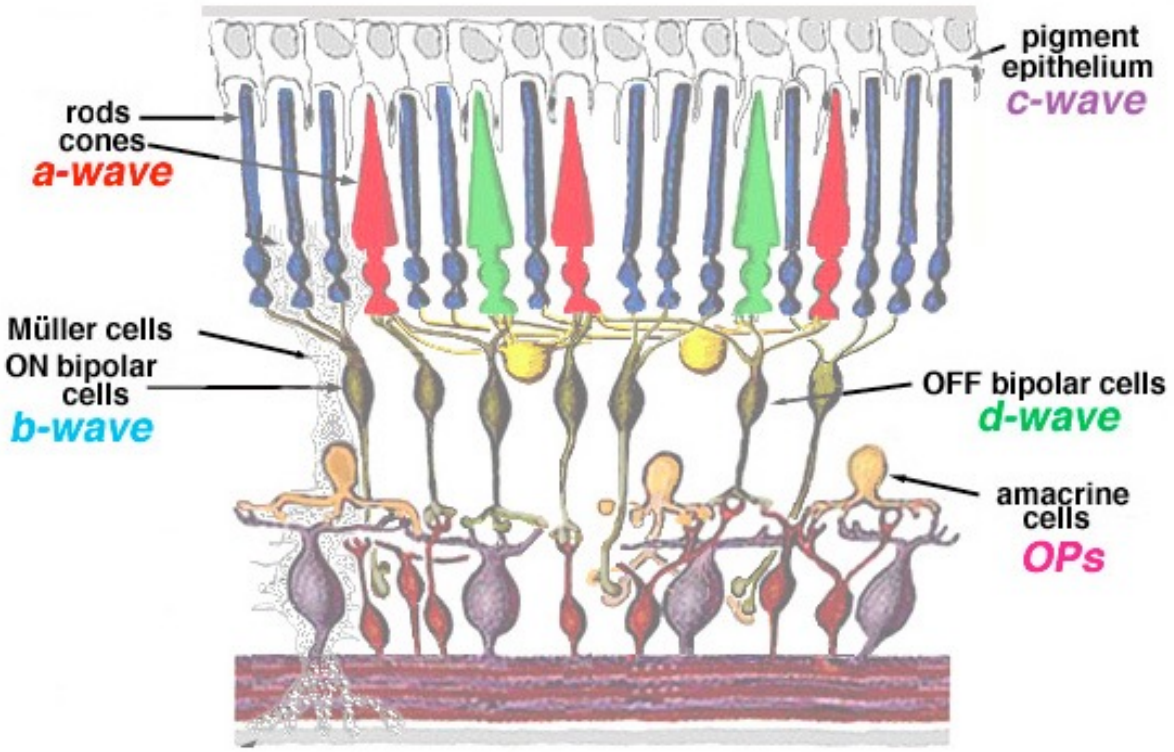
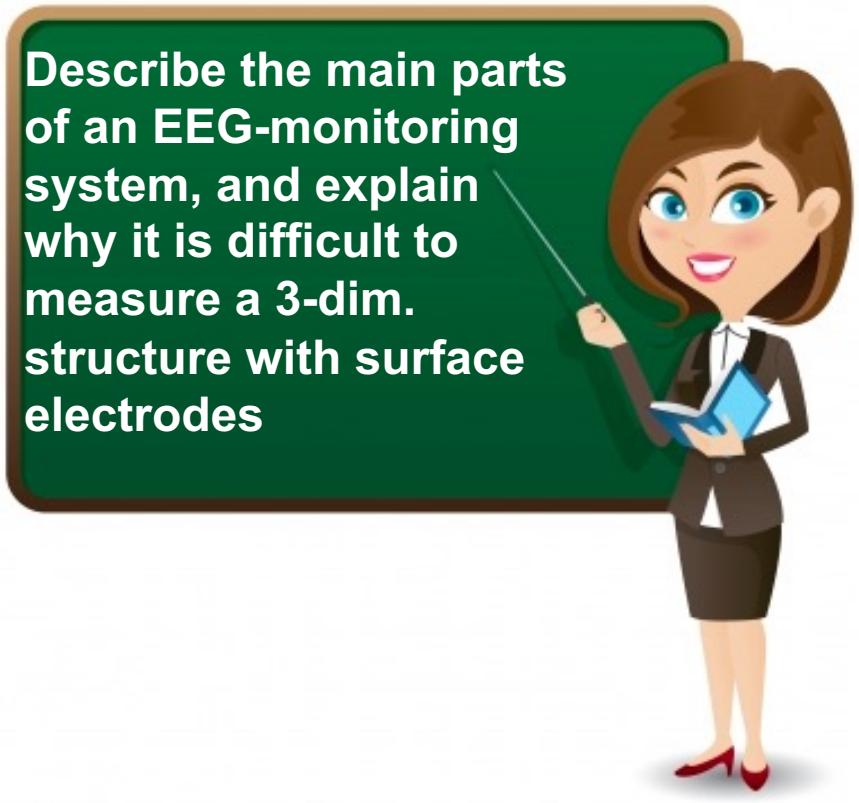
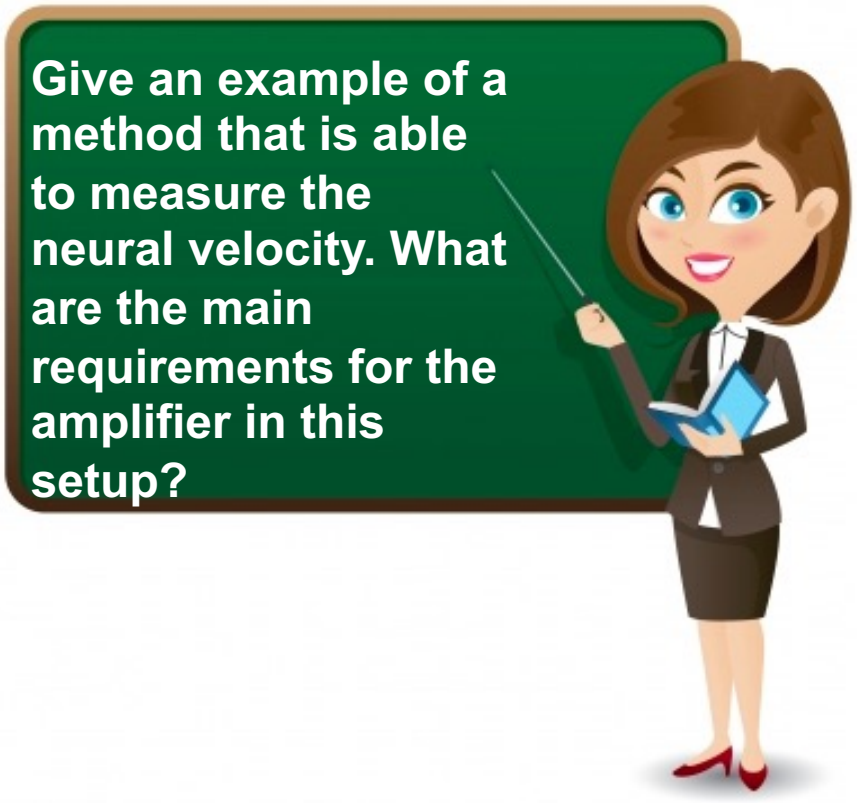


Fig.3 Cartoon of the retina to show where the major components of the ERG originate.

http://webvision.med.utah.edu/gifswv/DONFig3.gif

Exercise examples







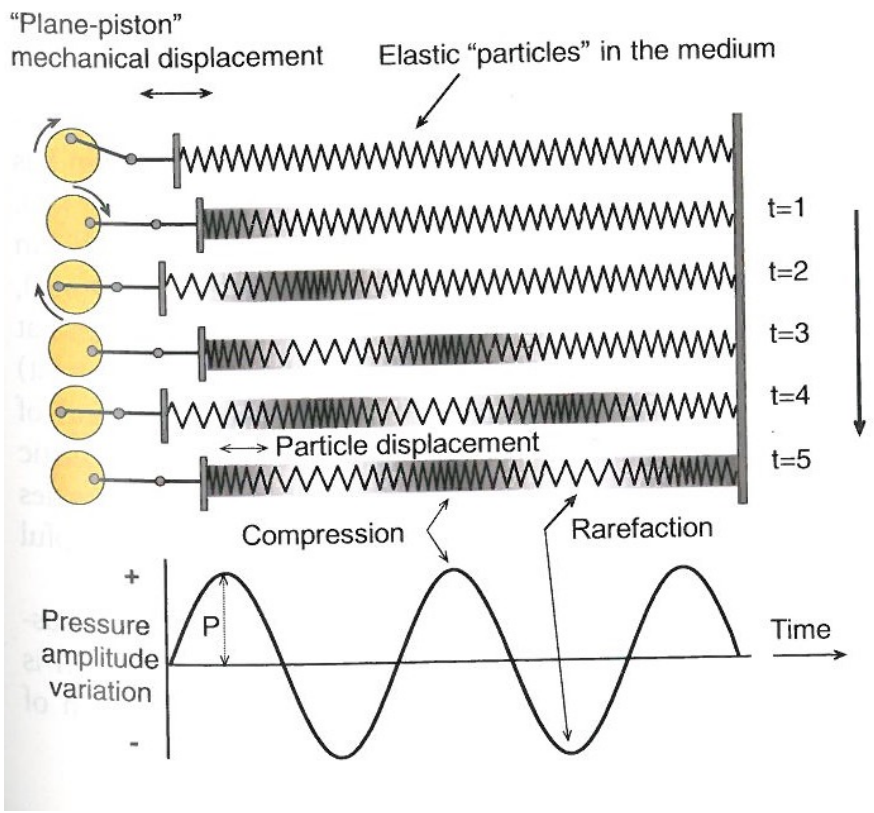
UiO : Department of Physics
University of Oslo

FYS 4250

Lecture 13



Ultrasound energy



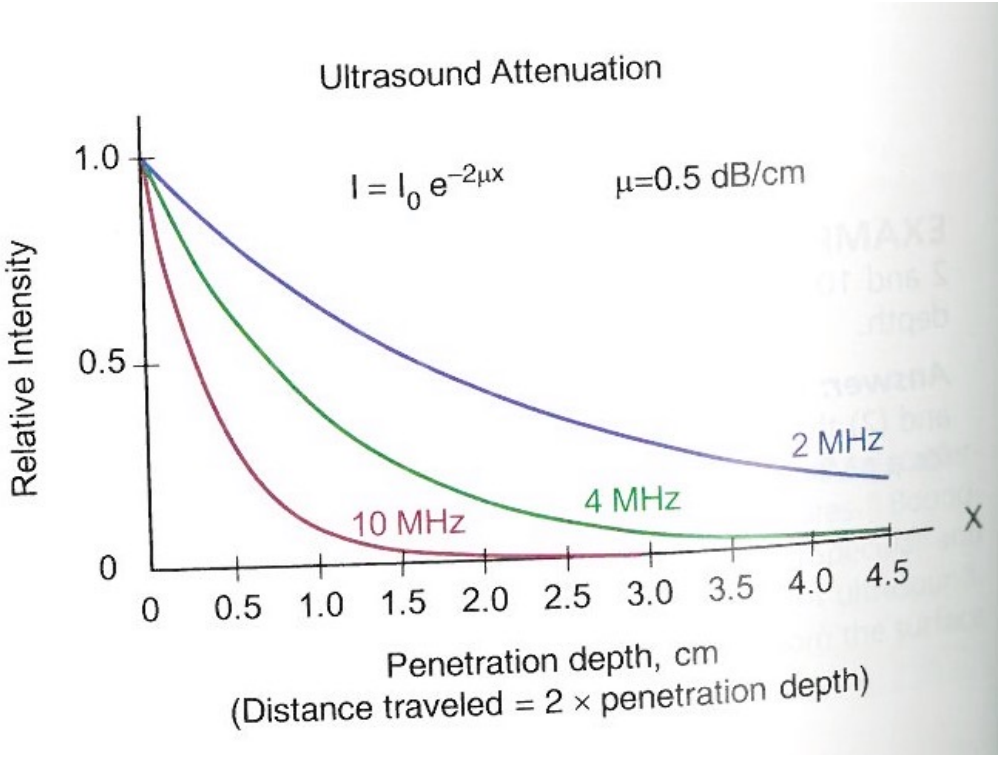
■ FIGURE 14-2 Ultrasound energy is generated by a mechanical displacement in compressible medium, which is modeled as an elastic spring. Energy propagation is shown as a function of time, resulting in areas of compression and rarefaction with corresponding variations in positive and negative pressure amplitude, *P* (lower diagram). Particles in the medium have only minor displacement as the wave front passes.

Bushberg et al, The essential physics of medical imaging



Ultrasound attenuation

■ FIGURE 14-7 Ultrasound attenuation occurs exponentially with penetration depth and increases with increased frequency. The plots are estimates of a single frequency ultrasound wave with an attenuation coefficient of (0.5 dB/cm)/MHz of ultrasound intensity versus penetration depth. Note that the total distance traveled by the ultrasound pulse and echo is twice the penetration depth.



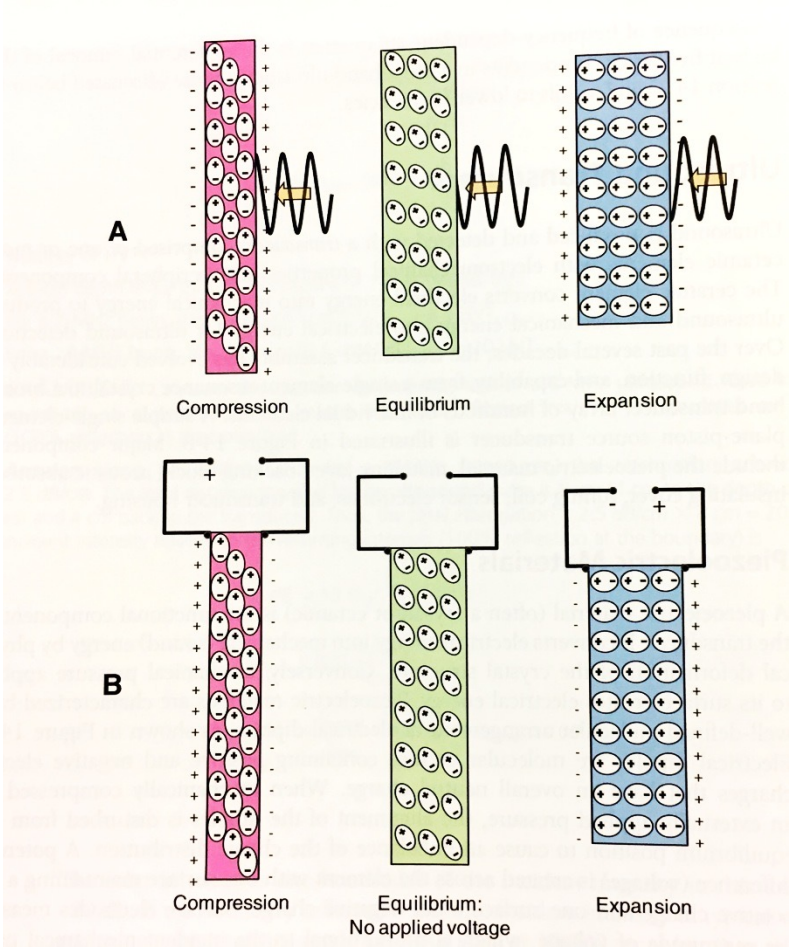
Some of the energy is scattered and lost when hitting small objects with size <= Landa. Absorbed energy is converted to heat. The transducer thickness defines the frequency, the thickness of the transducer equal to ½ Landa

The spatial resolution depends on wavelength, and the attenuation on the frequency

Total reflection, all of the beam is travelling along the boundary



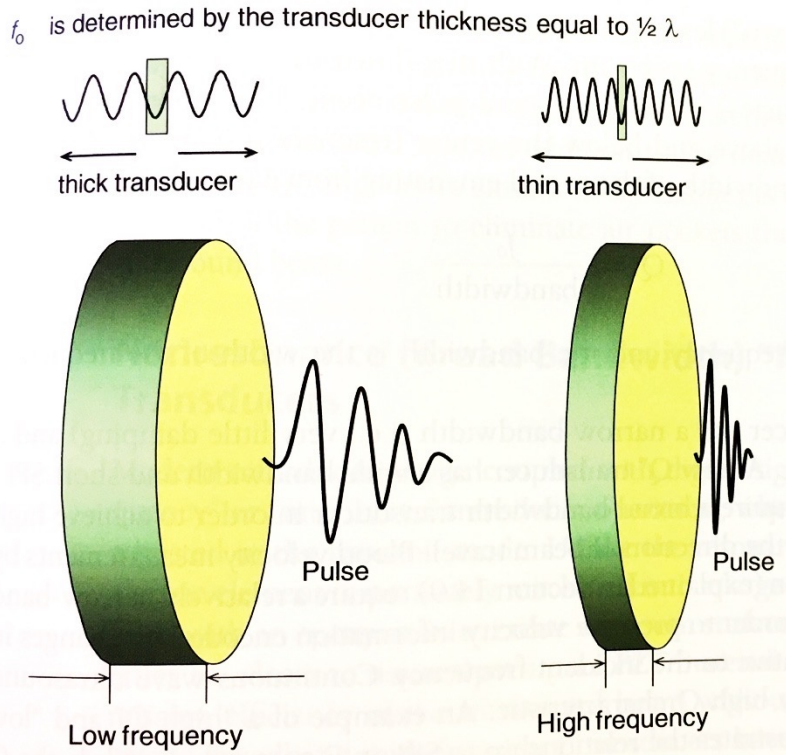
The piezoelectric element



A – under influence of mechanical pressure. Surface electrodes measure the charge variation as a function of time
B – External voltage source applied to surface causes compression or expansion from equilibririum -> realignment of the dipole

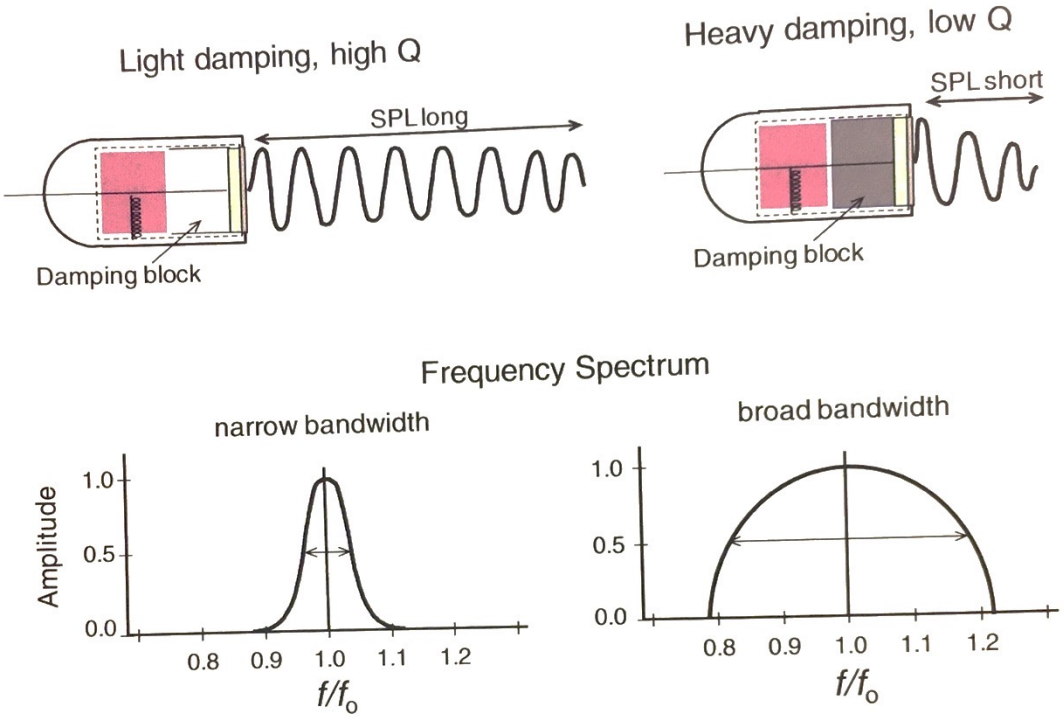
Bushberg et al, The essential physics of medical imaging

The piezoelectric element



■ **FIGURE 14-10** A short-duration voltage spike causes the resonance piezoelectric element to vibrate at its natural frequency, f_0, which is determined by the thickness of the transducer equal to ½ λ. Low-frequency oscillation is produced with a thicker piezoelectric element. The spatial pulse length (SPL) is a function of the operating frequency and the adjacent damping block.

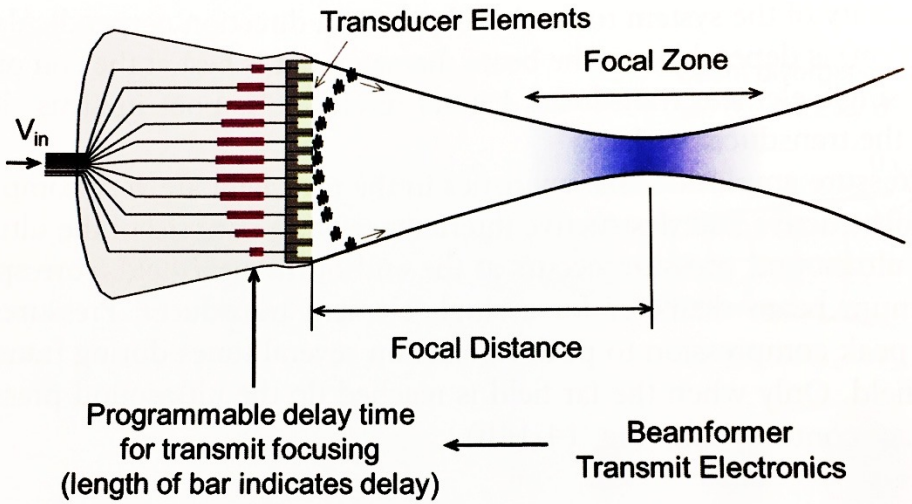
The damping block



■ **FIGURE 14-11** Effect of damping block on the frequency spectrum. The damping block is adjacent to the backside of the transducer and limits the vibration of the element to a small number of cycles. Light damping allows many cycles to occur (**top left**), which results in an extended SPL (number of cycles times the wavelength) and a narrow frequency bandwidth (range of frequencies contained in the pulse (**bottom left**). Heavy damping reduces the SPL and broadens the frequency bandwidth (**top and bottom right**). The Q factor describes the center frequency divided by the bandwidth.



The phased array transducer

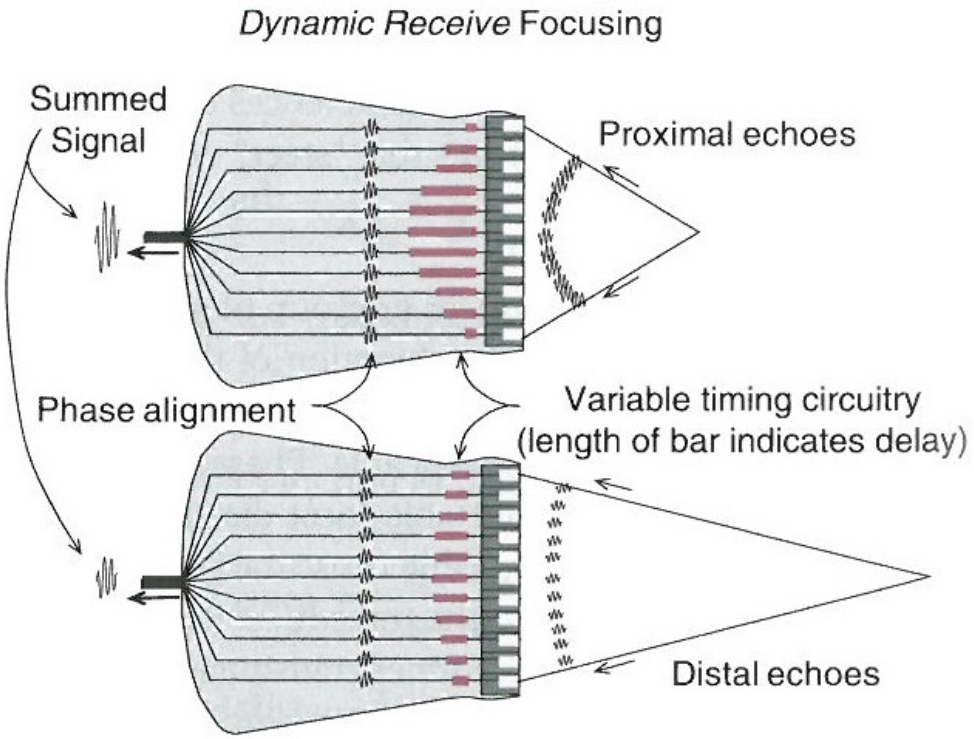


■ **FIGURE 14-15** A phased-array transducer assembly uses all elements to produce the ultrasound beam. Focusing is achieved by implementing a programmable delay time (beam former electronics) for the excitation of the individual transducer elements (focusing requires the outer elements in the array be energized first). Phase differences of the individual ultrasound pulses result in a minimum beam diameter (the focal distance) at a predictable depth in tissue.



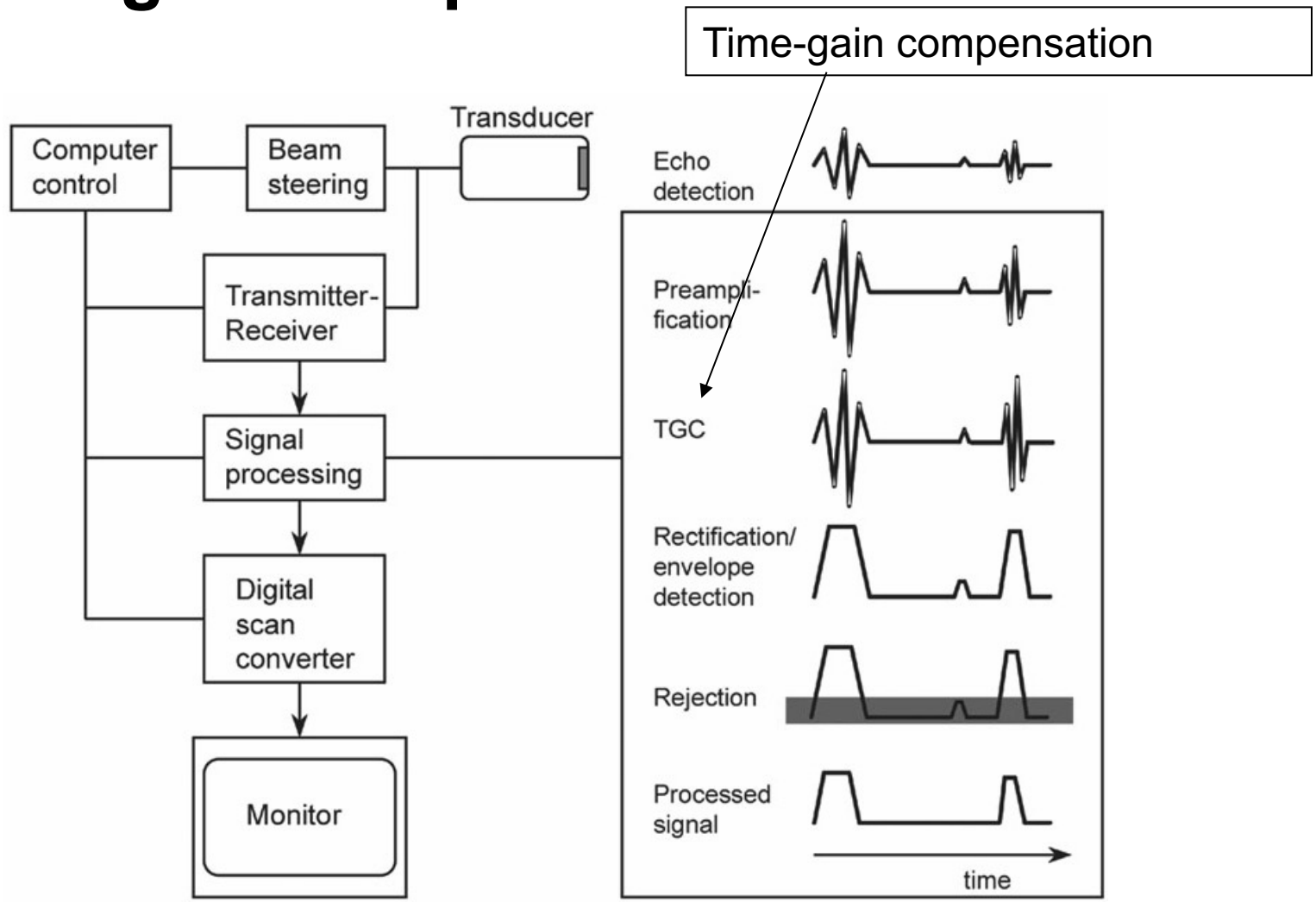
Dynamic receive focusing

■ FIGURE 14-16 Dynamic receive focusing. All transducer elements in the phased array are active during the receive mode, and to maintain focus, the receive focus timing must be continuously adjusted in order to compensate for differences in arrival time across the array as a function of time (depth of the echo). Depicted are an early time (top illustration) of proximal echo arrival and a later time of distal echo arrival. To achieve phase alignment of the echo responses by all elements, variable timing is implemented as a function of element position after the transmit pulse in the beam former. The output of all phase-aligned echoes is summed.





Time-gain compensation

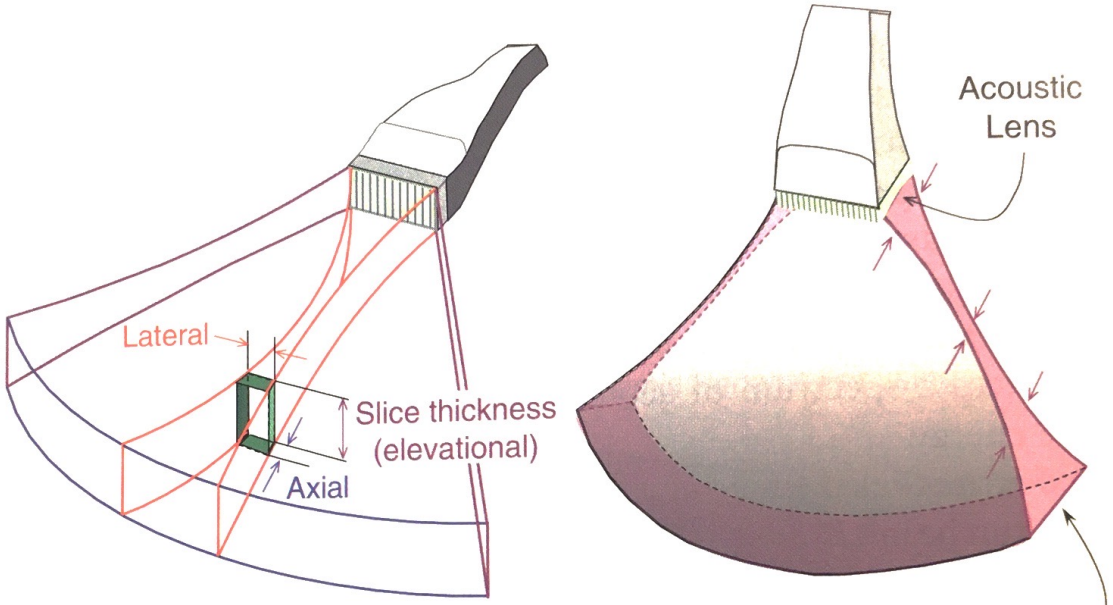


Kilde: Alejandro Frangi

Time-gain compensation: Reducing artifacts in the B-mode intensity images by increasing intensity with depth



Resolution



A Resolution components in 3-D space. **B** Elevational Profile of Ultrasound Beam with depth

■ **FIGURE 14-19** **A.** The axial, lateral, and elevational (slice-thickness) contributions in three dimensions are shown for a phased-array transducer ultrasound beam. Axial resolution, along the direction of the beam, is independent of depth; lateral resolution and elevational resolution are strongly depth dependent. Lateral resolution is determined by transmit and receive focus electronics; elevational resolution is determined by the height of the transducer elements. At the focal distance, axial is better than lateral and lateral is better than elevational resolution. **B.** Elevational resolution profile with an acoustic lens across the transducer array produces a focal zone in the slice-thickness direction.

Bushberg et al, The essential physics of medical imaging



Ultrasound (US), A-mode (amplitude)

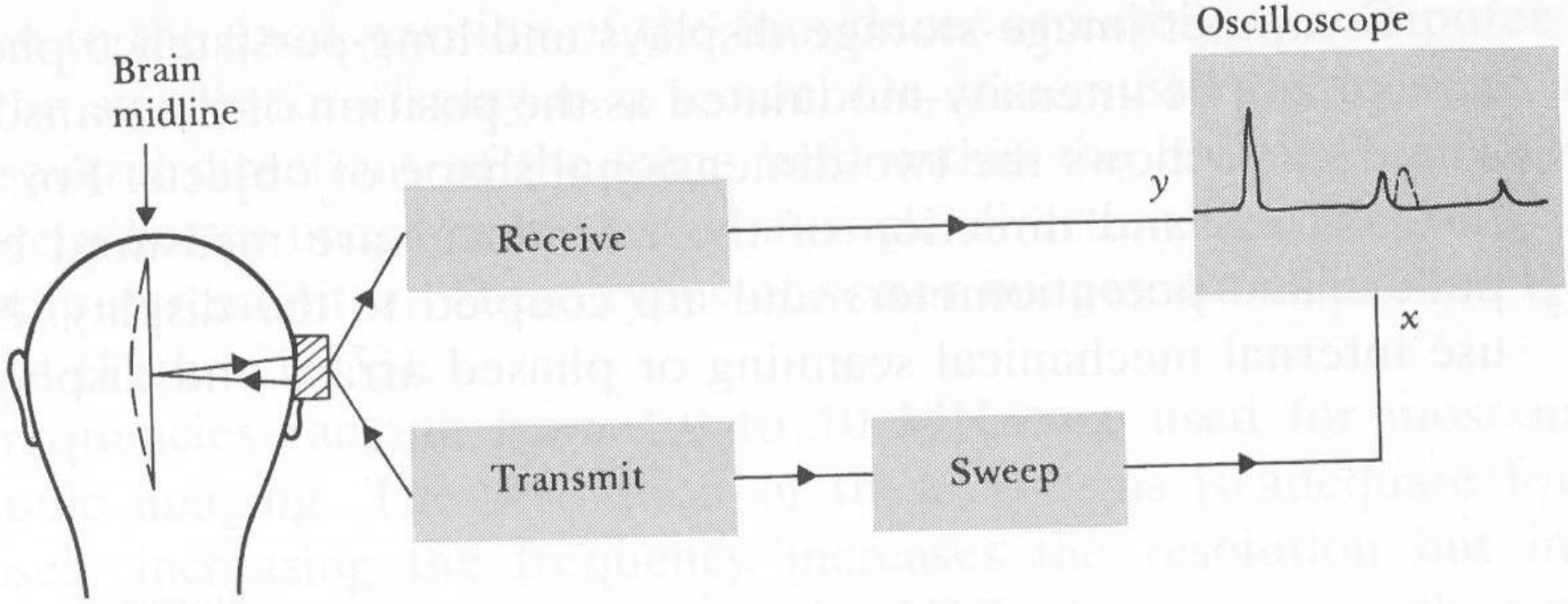


Figure 12.31 A-mode scan of the brain midline

Time delay between transmitted pulse and its echo is a maesure of the depth of the tissue interface
Each change of tissue type, a reflection results
Displacement of the brain midline. Scanning from both sides, should be symmetric, a tumor or blood clot could move the cerebral hemispheres to shift the midline
Obsolete now

Time motion US, M-mode

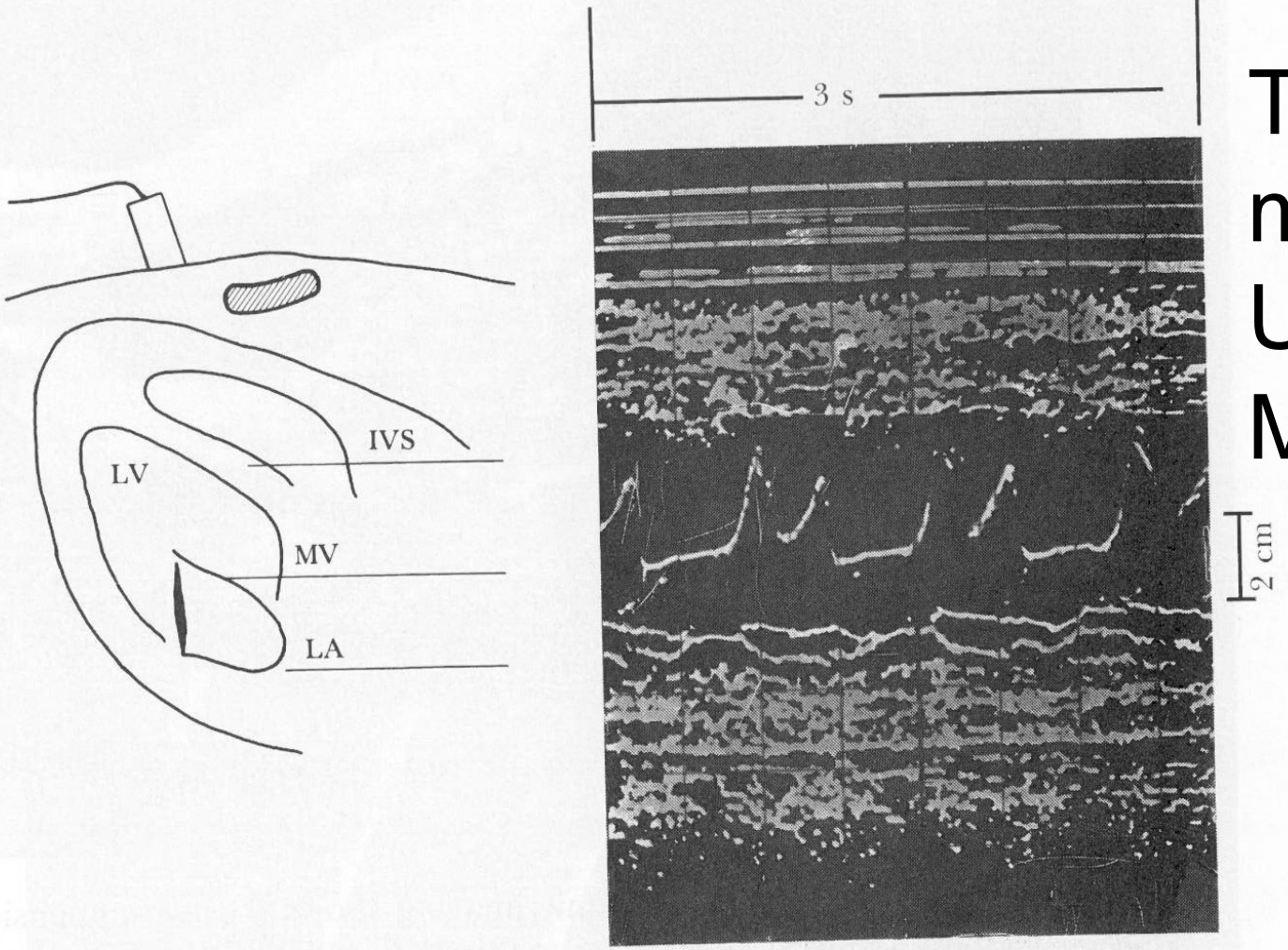


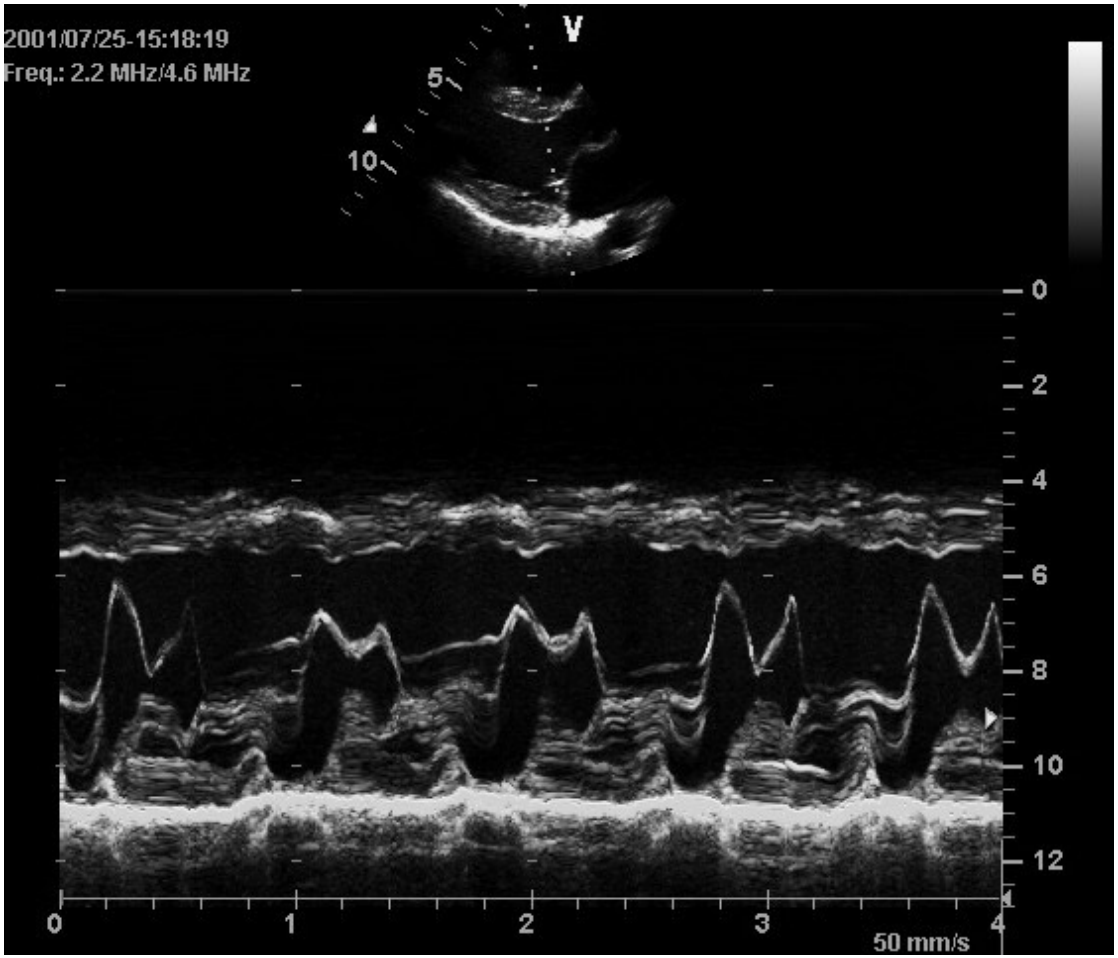
Figure 12.32 **Time-motion ultrasound scan of the mitral valve of the heart** The central trace follows the motions of the mitral valve (MV) over a 3-s period, encompassing three cardiac cycles. The other traces correspond to other relatively static structures, such as the interventricular septum (IVS) and the walls of the left atrium (LA).

Strength of the echo is used to modulate intensity of the display against echo-return time with zero time at the top of the display, image can be shown as moving to the right.

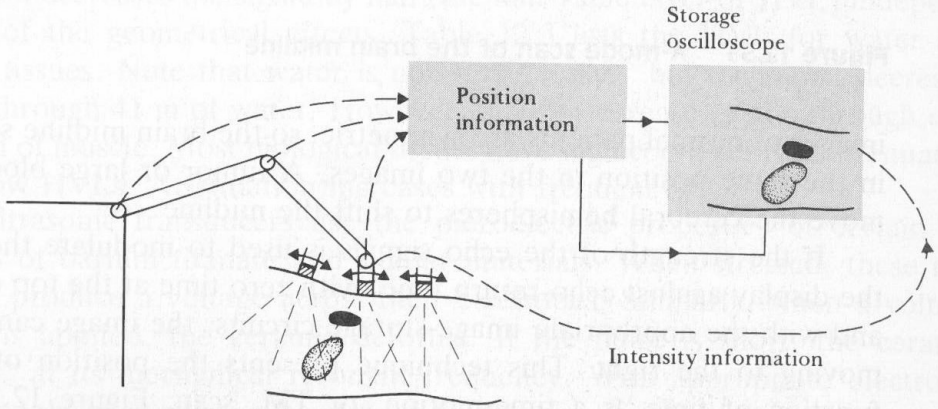
Position of tissues as a function of time = Time motion scan



M-mode Ultrasound (motion)



UiO



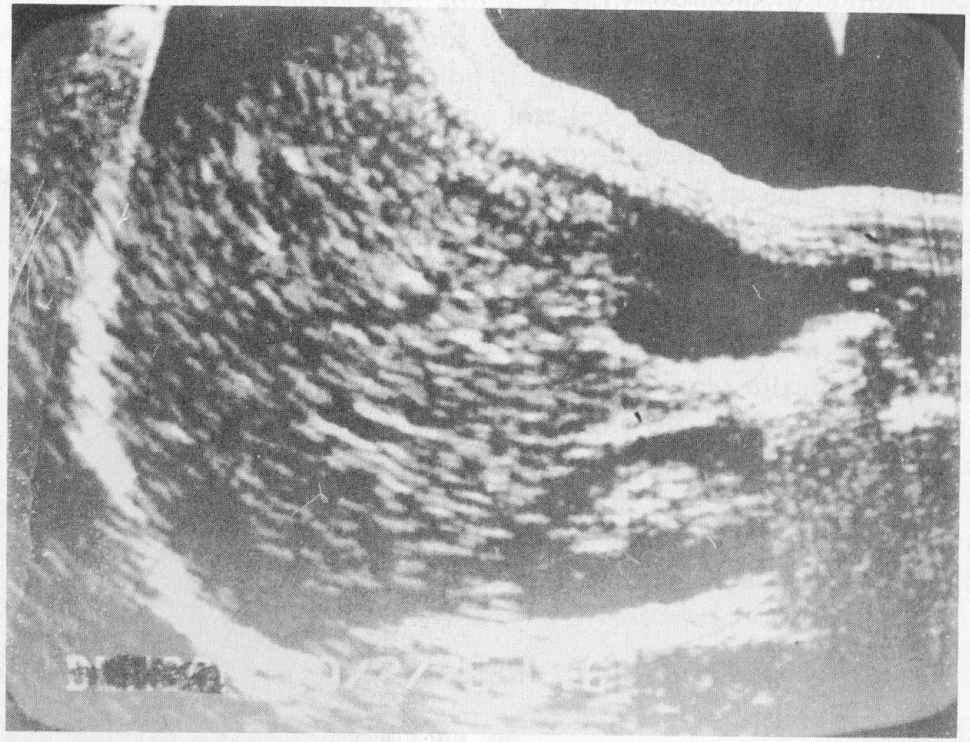


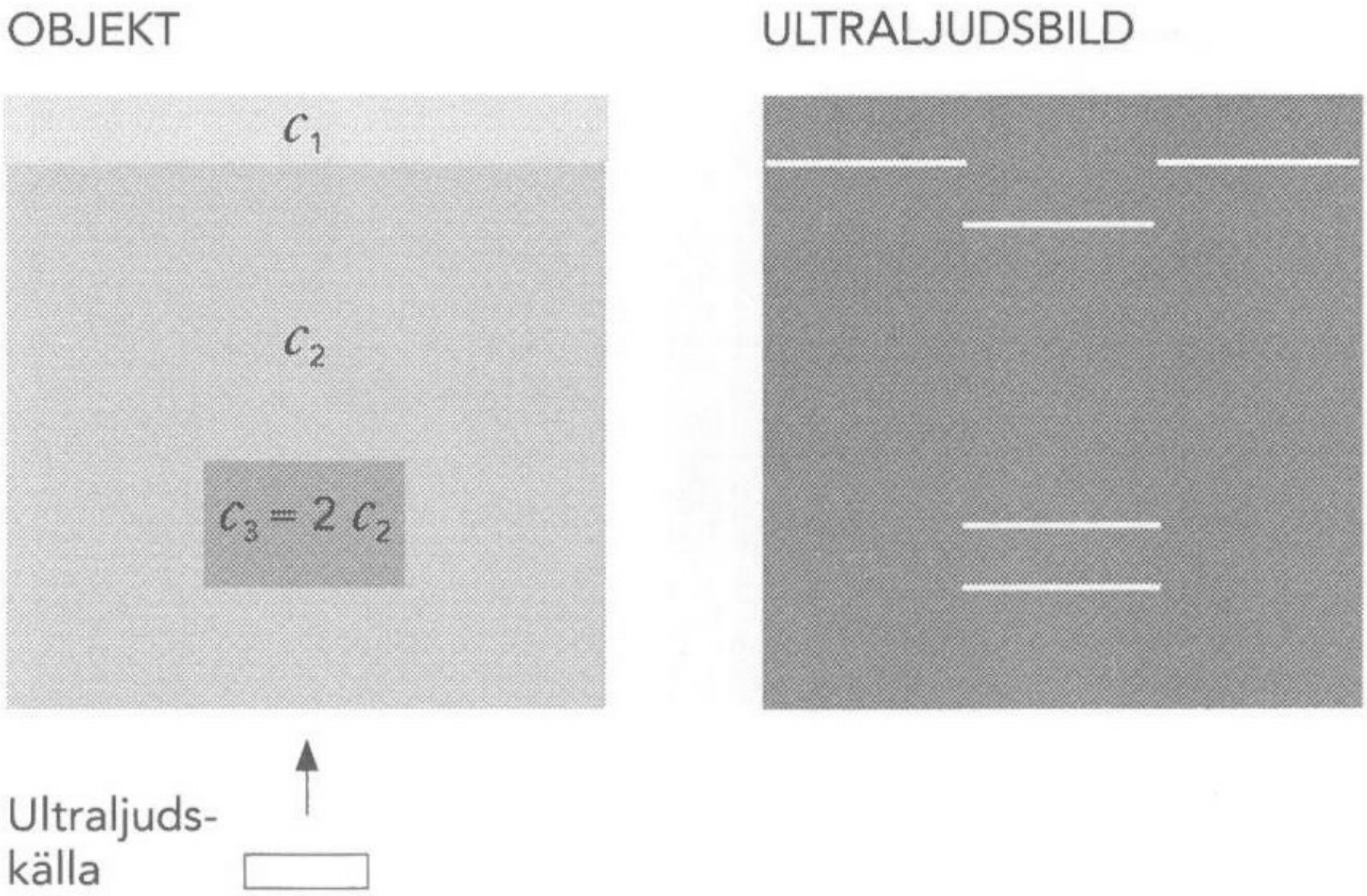
Figure 12.33 (a) B-mode ultrasonic imaging shows the two-dimensional shape and reflectivity of objects by using multiple-scan paths. (b) This B-mode ultrasonic image, which corresponds to (a), shows the skin of the belly at the top right, the liver at the left center, the gall bladder at the right above center, and the kidney at the right below center. The bright areas within the kidney are the collecting ducts.



B-mode

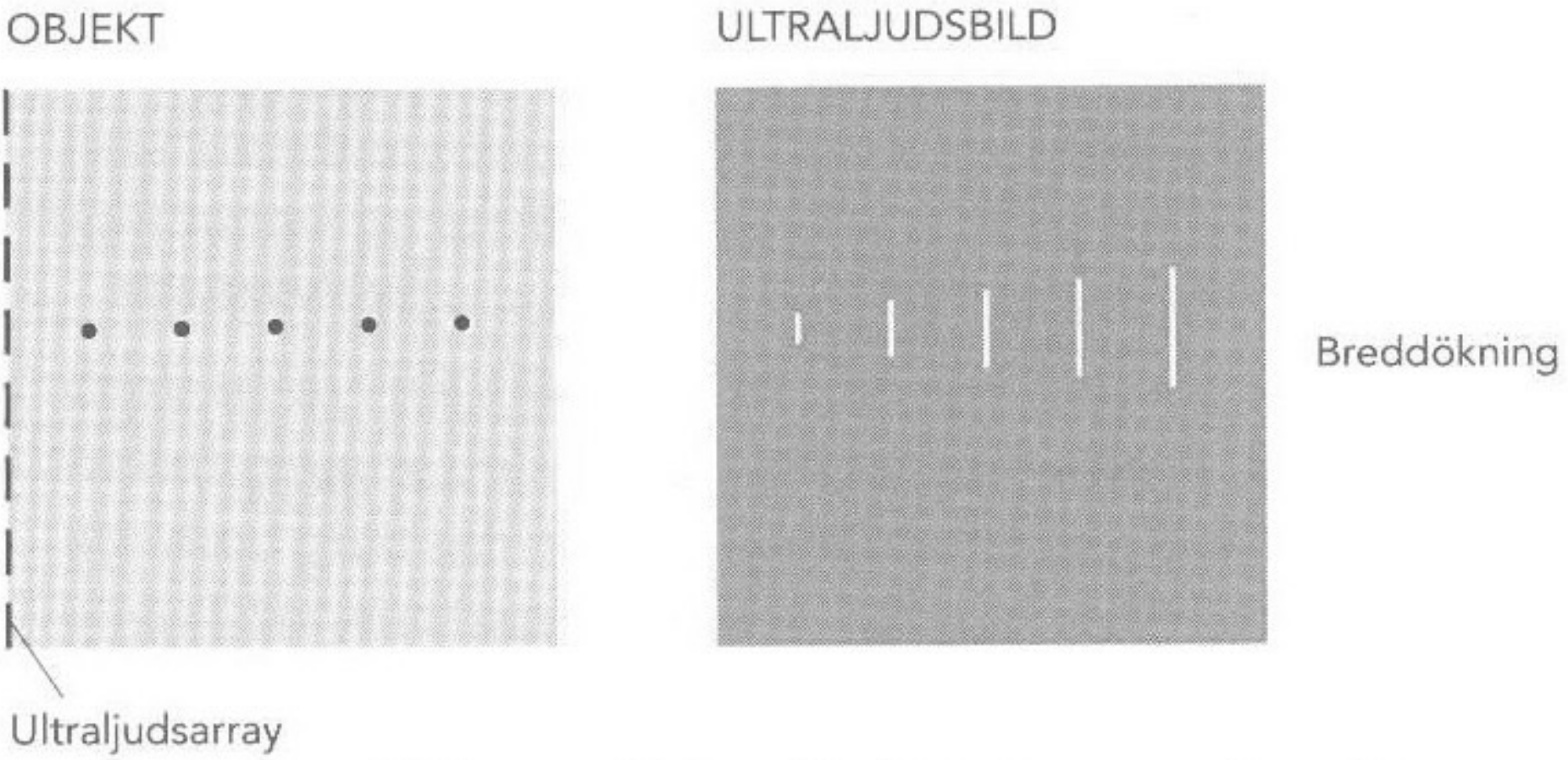
Sources of error (1)







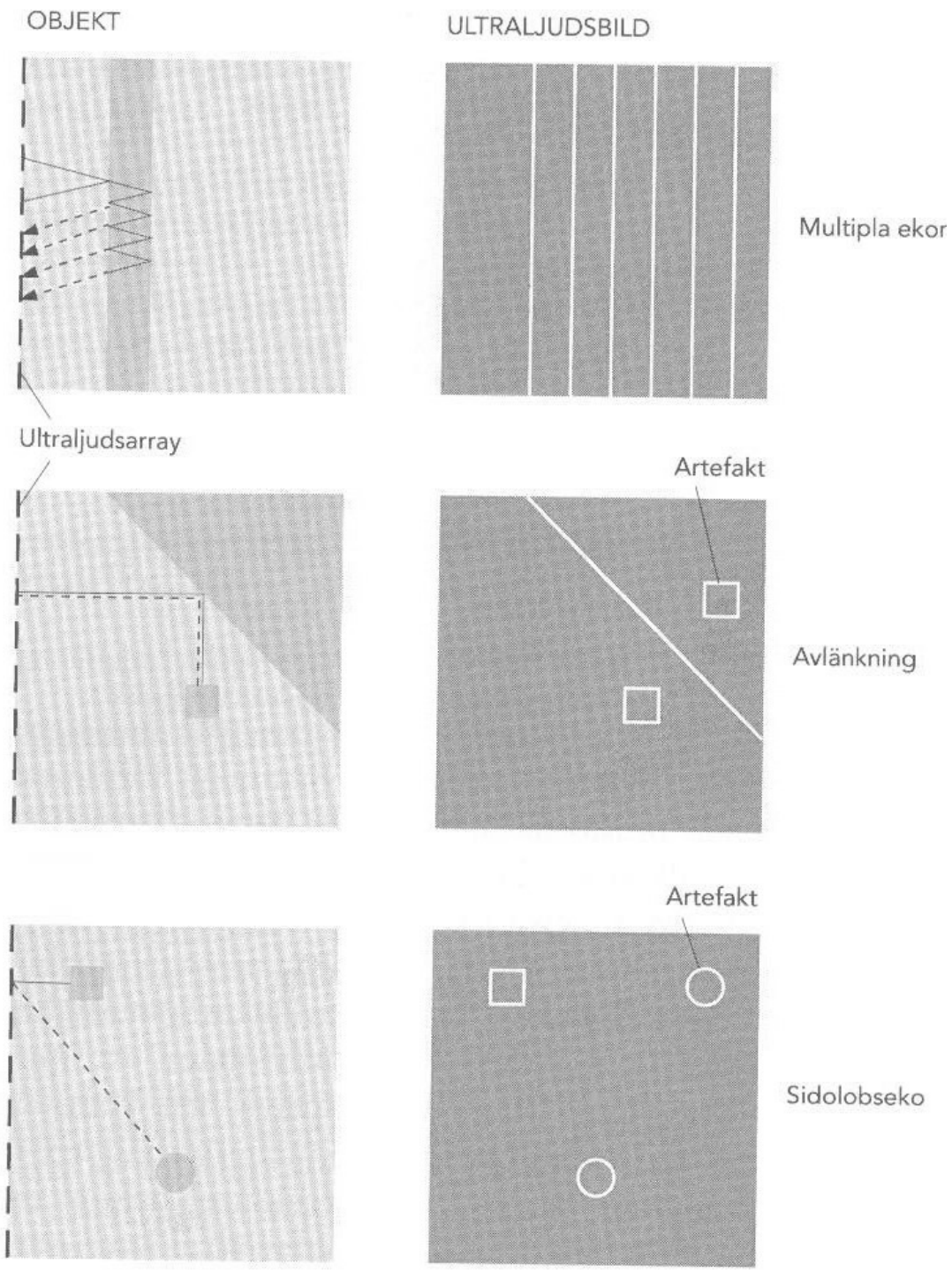
Sources of error (2)



UiO :



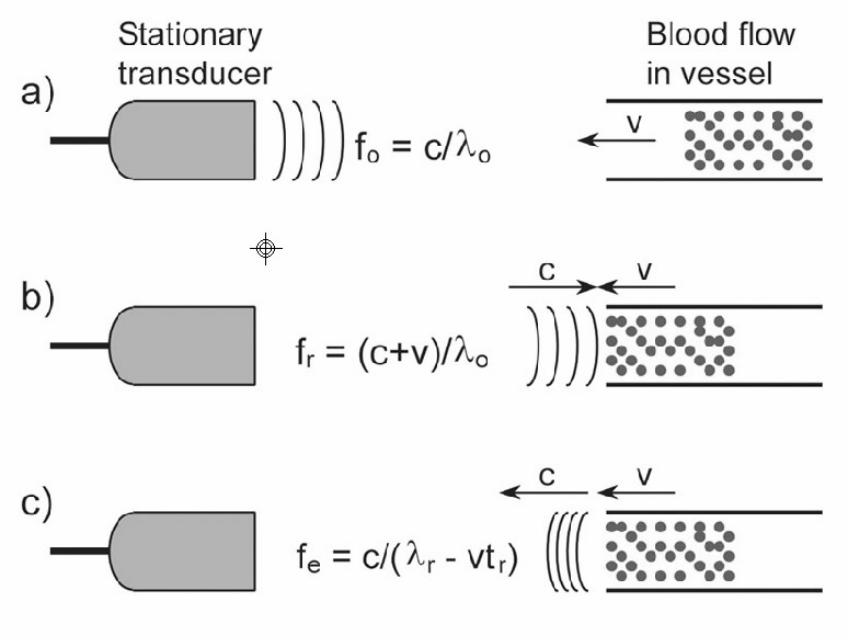
Sources of error (3,4,5)



Doppler ultrasound

Higher frequency = blood towards the transducer

Lower frequency = blood away from the transducer

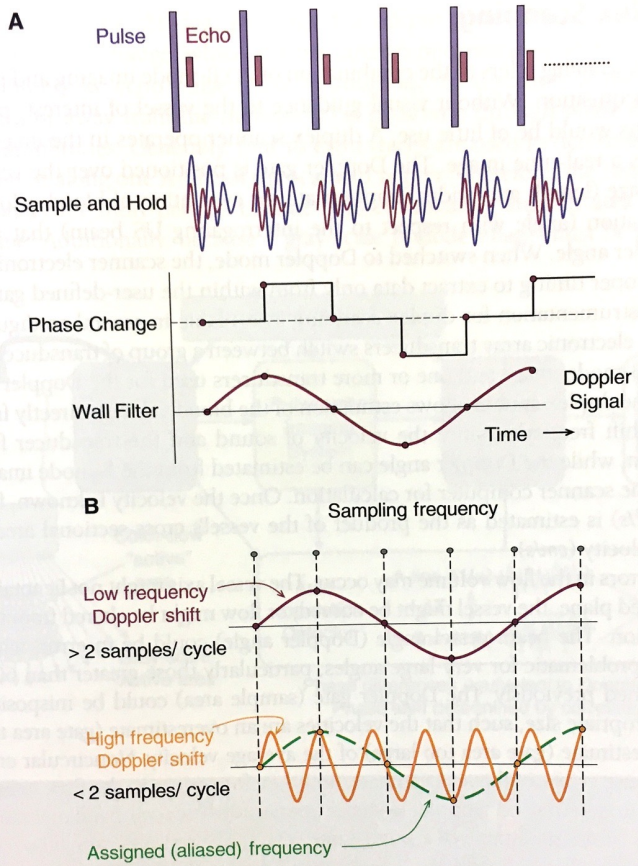


$$f_D = f_e - f_0 = 2 f_0 \frac{v \cdot \cos\alpha}{c}$$

Kilde: Alejandro Frangi

Doppler Ultrasound Aliasing





■ FIGURE 14-40 **A.** The returning ultrasound pulses from the Doppler gate are sampled over several pulse-echo cycles (in this example, six times), in order to estimate Doppler shifts (if any) caused by moving blood cells. A sample and hold circuit measures a variation of signal with time (note that the echo [***purple line***] and the pulse [***blue line***] vary in phase, which are recorded and analyzed by Fourier transform methods to determine the Doppler shift frequencies). The wall filter removes the low-frequency degradations caused by transducer and patient motion. **B.** Aliasing occurs when the frequencies in the sampled signal are greater than ½ the PRF (sampling frequency). In this example, a signal of twice the frequency is analyzed as if it were the lower frequency and thus mimics (aliases) the lower frequency.

Bushberg et al, The essential physics of medical imaging

Color doppler

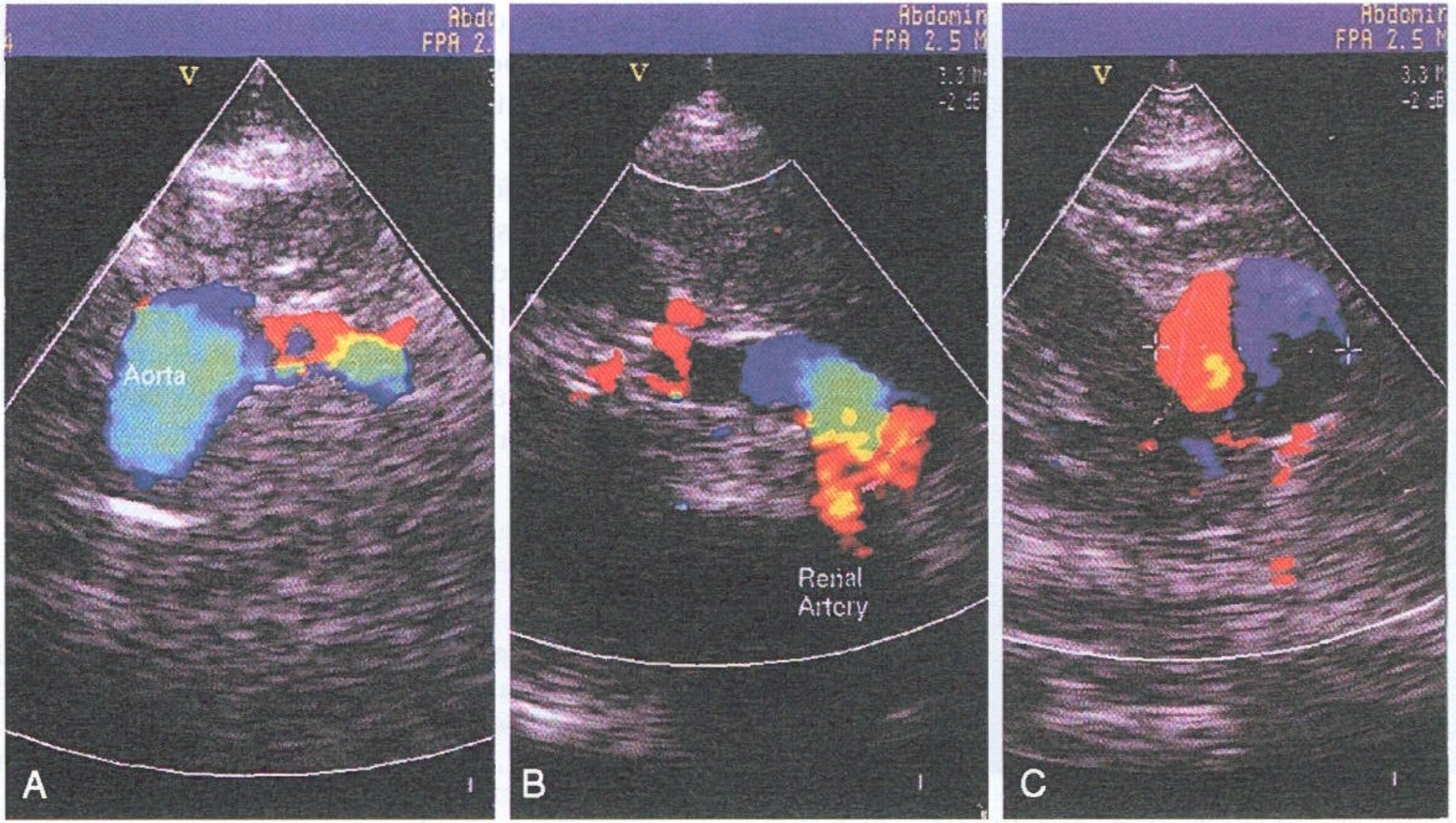


Fig. 1. A–C. Colour ultrasonography examination shows the dilated, tortuous left renal artery. A large aneurysm, partially exophytic, can be seen at the lower pole of the kidney. There is coexistence of both arterial and venous blood flow.



Ultrasound advantages

- Muscles and soft tissue are suitable for US-imaging, especially transitions between solid substances and liquid filled areas.
- Real time images = fast diagnosis. Can also be used to biopsy-guiding
- Shows the organ structure
- No well-known side effects, not unpleasant for the patient
- Small scanners compared to other image modalities
- Inexpensive compared to other image modalities
- Spatial resolution is better at high-frequency US than most of the other modalities



Ultrasound disadvantages

- Unable to penetrate bone tissue
- Poor performance where gas is present
- Limited operating range, dependent on the frequency
- High requrements for the operator, can be difficult to interpret
- Difficult to track back a scanned volume, as soon as the pictures are aquired no exact anchor-pile is available to navigate in the volume



Advantages focused ultrasound

- High accuracy (diameter of a few cells)
- Destroyed tissue will be re-absorbed of the body
- Rapid heating of the tissue will destroy the tumor
- Non-invasive or minimal invasive
- No blood loss
- Repeatable
- Rapid convalescence

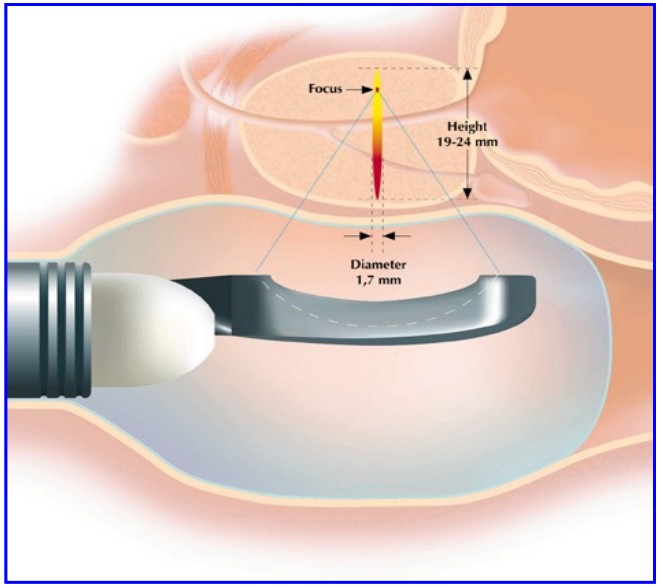
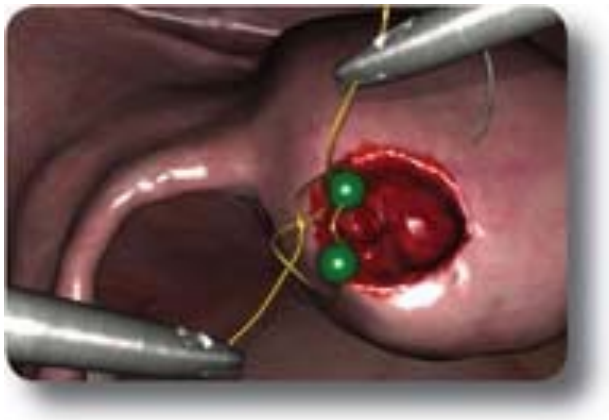


Image: Trans-rectal probe (EDAP)

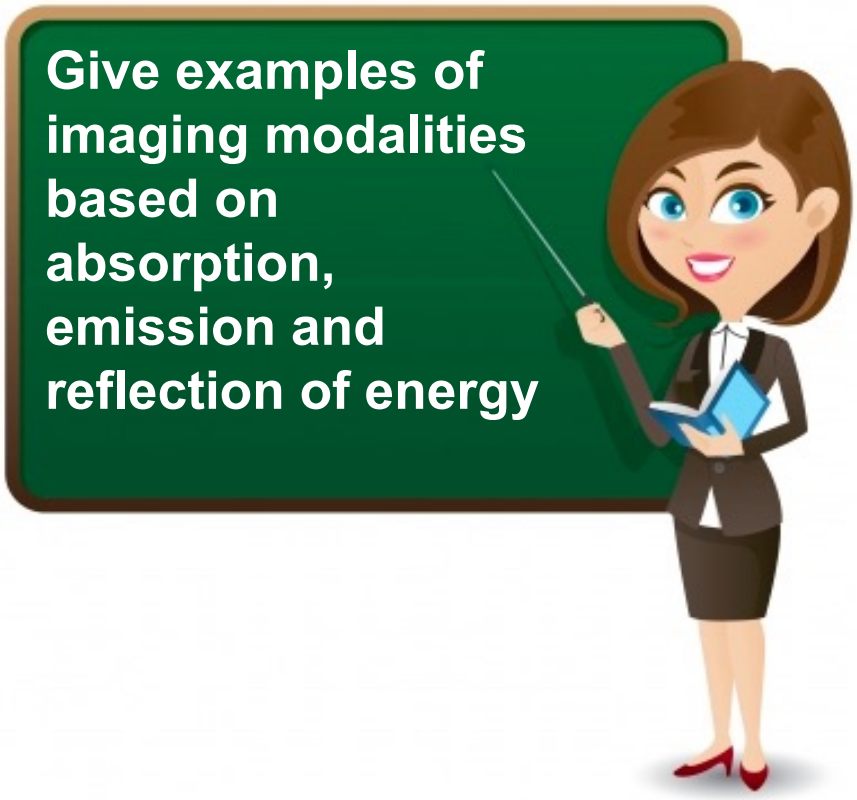


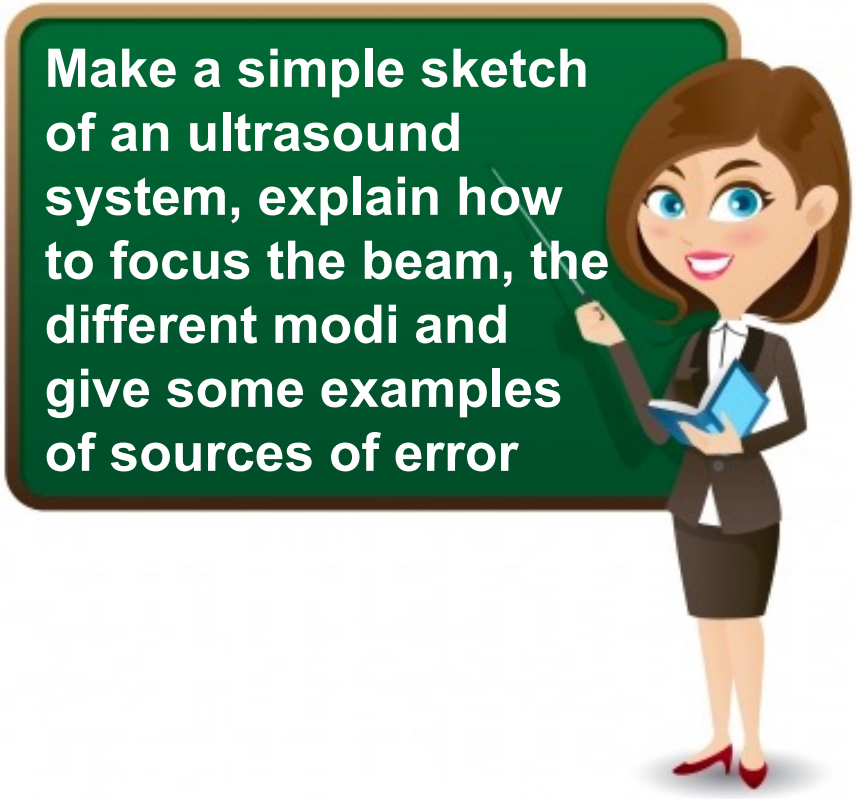
Disadvantages focused ultrasound

- Capacity problems with large tumors
- New and not established procedure
- Needs direct acoustic access to tumor
- The tumor must be well defined
- The surgeon will not have direct vision of the tissue with the tumor
- Possible side effects of high energetic ultrasound is not clarified (10^4 of the energy of imaging ultrasound)
- Require normally MR-monitoring to verify necrosis



Exercise examples







UiO : Department of Physics
University of Oslo

FYS 4250

Lecture 14



Energy levels of free protons

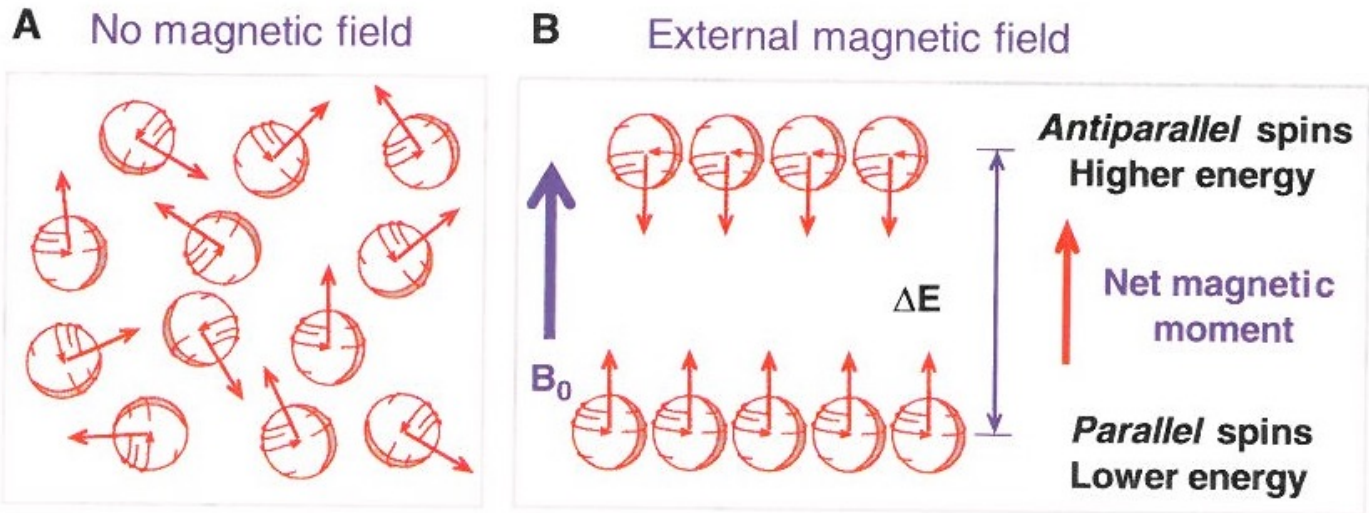
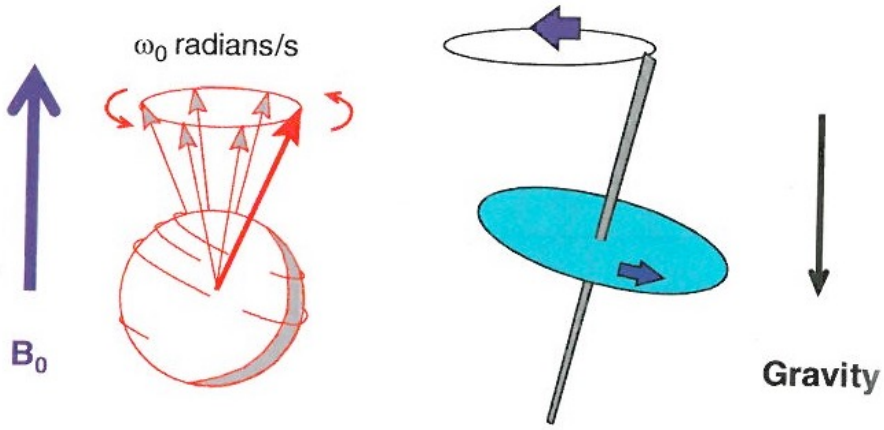


FIGURE 12-7 Simplified distributions of "free" protons without and with an external magnetic field are shown. **A.** Without an external magnetic field, a group of protons assumes a random orientation of magnetic moments, producing an overall magnetic moment of zero. **B.** Under the influence of an applied external magnetic field, B_0, the protons assume a nonrandom alignment in two possible orientations: parallel and antiparallel to the applied magnetic field. A slightly greater number of protons exist in the parallel direction, resulting in a measurable *net magnetic moment* in the direction of B_0.

Magnetic characteristics of nucleus

$W_0 = \gamma B_0$

■ FIGURE 12-8 A single proton *precesses* about its axis with an angular frequency, ω, proportional to the externally applied magnetic field strength, according to the *Larmor* equation. A well-known example of precession is the motion a spinning top makes as it interacts with the force of gravity as it slows.

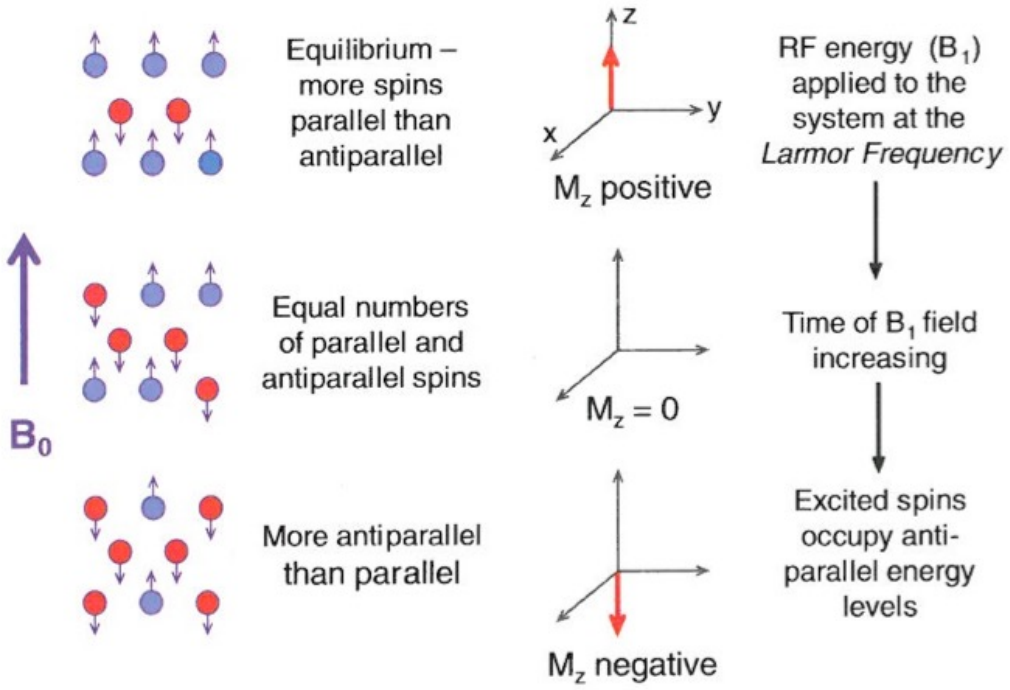


Precessional frequency

$$f_0 = \frac{\gamma}{2\pi} B_0$$

In addition to spin, there is a torque in a perpendicular direction from the applied magnetic field that causes precession. The Larmor equation describes the dependence between the magnetic field B0 and the angular precessional frequency w0.

Resonance and exitation



■ FIGURE 12-12 A simple quantum mechanics process depicts the discrete energy absorption and the time change of the longitudinal magnetization vector as RF energy equal to the energy difference of the parallel and antiparallel spins is applied to the sample (at the Larmor frequency). Discrete quanta absorption changes the proton energy from parallel to antiparallel. With continued application of the RF energy at the Larmor frequency, M_z is displaced from equilibrium, through zero, to the opposite direction (high energy state).



Larmor frequency

The energy difference between the two alignment states depends on the nucleus

$$\Delta E = 2\ \mu_z B_o$$
$$\Delta E = h\ \nu$$

$$\nu = (\gamma/2\pi)\ B_o$$

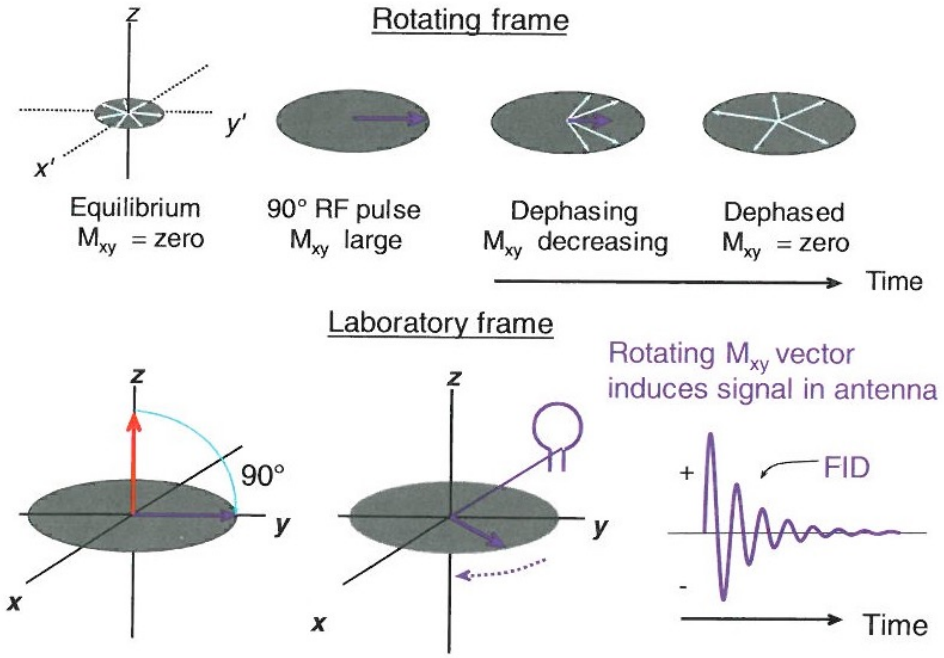
known as Larmor frequency

$\gamma/2\pi$ = 42.57 MHz / Tesla for proton



Free induction decay = a damped sinusoidal electronic signal

Dephasing of magnetic vector



■ FIGURE 12-15 **Top.** Conversion of longitudinal magnetization, M_z, into transverse magnetization, M_{xy}, results in an initial phase coherence of the individual spins of the sample. The magnetic moment vector precesses at the Larmor frequency (stationary in the rotating frame), and dephases with time. **Bottom.** In the laboratory frame, M_{xy} precesses and induces a signal in an antenna receiver sensitive to transverse magnetization. A FID signal is produced with positive and negative variations oscillating at the Larmor frequency, and decaying with time due to the loss of phase coherence.

Bushberg et al, The essential physics of medical imaging



Return to equilibrium, T1 relaxation

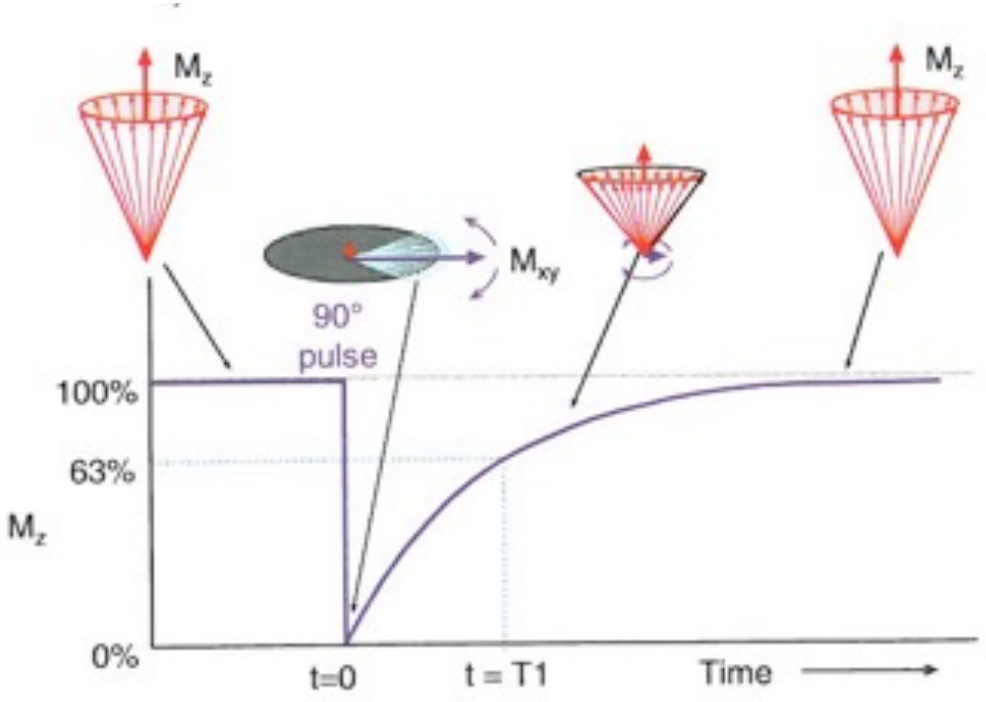
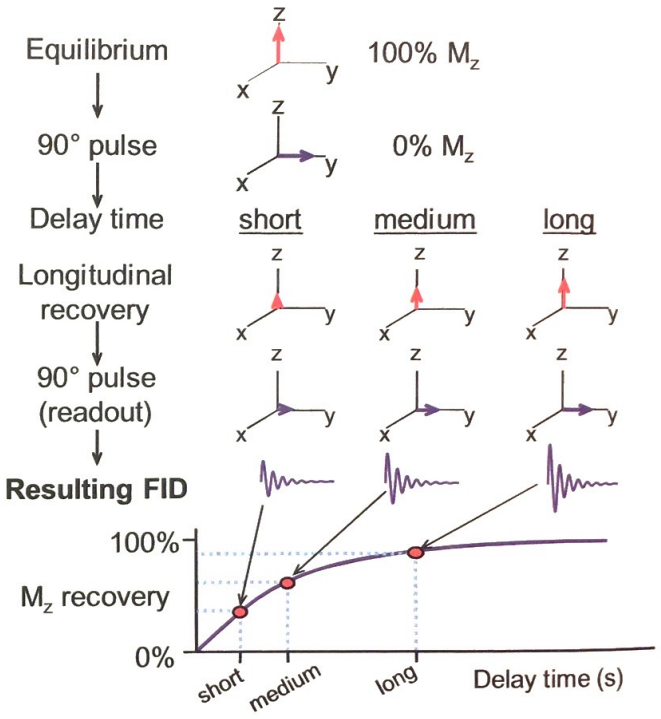


FIGURE 12-17 After a 90-degree pulse, M_z is converted from a maximum value at equilibrium to $M_z = 0$. Return of M_z to equilibrium occurs exponentially and is characterized by the spin-lattice T1 relaxation constant. After an elapsed time equal to T1, 63% of the longitudinal magnetization is recovered. Spin-lattice recovery takes longer than spin-spin decay (T2).

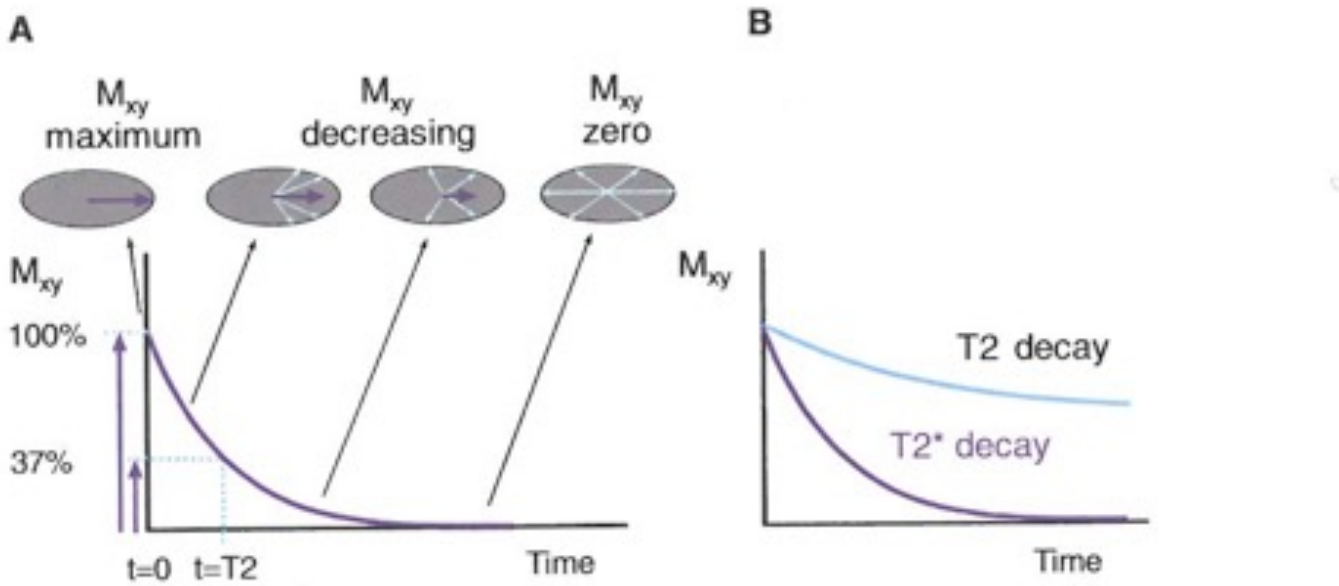
Return to equilibrium, T1 relaxation

■ **FIGURE 12-18** Spin-lattice relaxation for a sample can be measured by using various delay times between two 90-degree RF pulses. After an initial 90-degree pulse, $M_z = 0$, another 90-degree pulse separated by a known delay is applied, and the longitudinal magnetization that has recovered during the delay is converted to transverse magnetization. The maximum amplitude of the resultant FID is recorded as a function of delay times between initial pulse and readout (three different delay time experiments are shown in this example), and the points are fit to an exponential recovery function to determine T1.





Free induction decay: T2 Relaxation



■ FIGURE 12-16 **A.** The loss of M_{xy} phase coherence occurs exponentially caused by intrinsic spin-spin interactions in the tissues and extrinsic magnetic field inhomogeneities. The exponential decay constant, T2, is the time over which the signal decays to 37% of the initial transverse magnetization (e.g., after a 90-degree pulse). **B.** T2 is the decay time resulting from *intrinsic* magnetic properties of the sample. T2* is the decay time resulting from *both intrinsic and extrinsic magnetic field variations*. T2 is always longer than T2*.

Bushberg et al, The essential physics of medical imaging

Comparison of T1 and T2

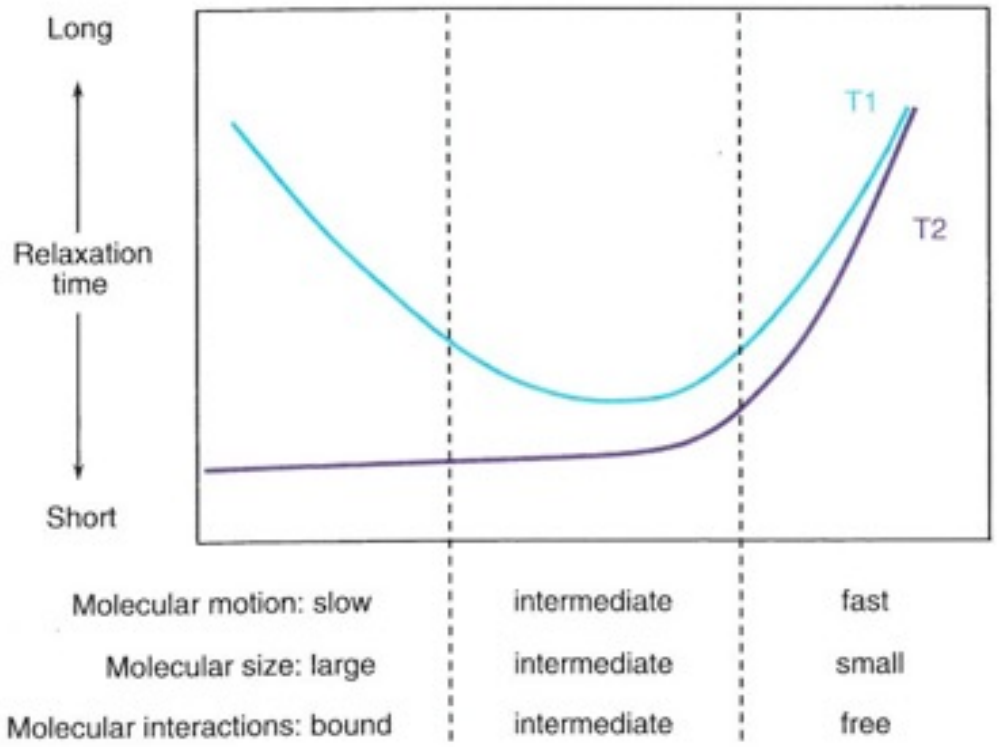


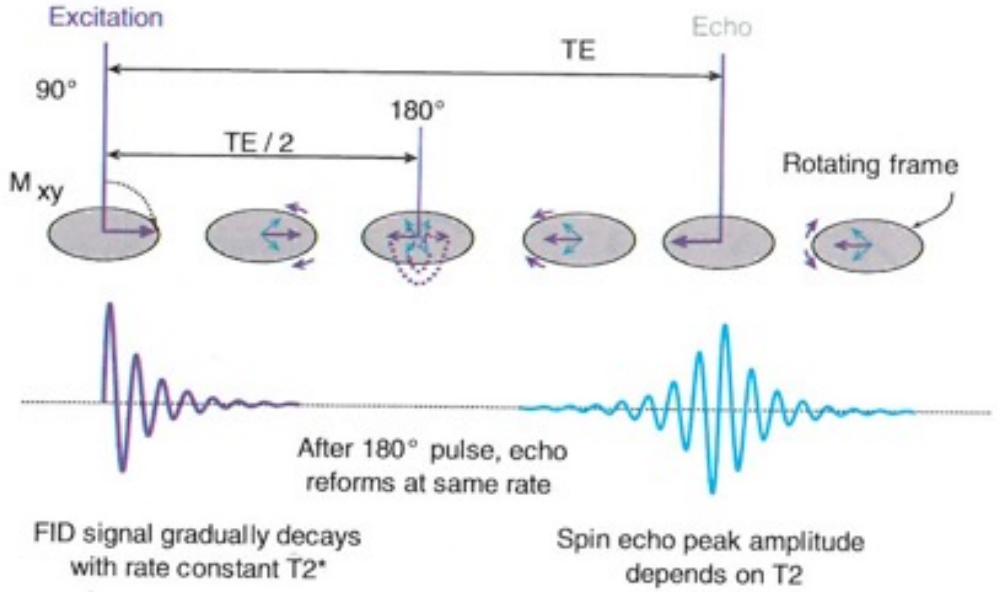
FIGURE 12-20 Factors affecting T1 and T2 relaxation times of different tissues are generally based on molecular motion, size, and interactions that have an impact on the local magnetic field variations (T2 decay) and structure with intrinsic tumbling frequencies coupling to the Larmor frequency (T1 recovery). The relaxation times (vertical axis) are different for T1 and T2.

Bushberg et al, The essential physics of medical imaging



Spin echo contrast weighting

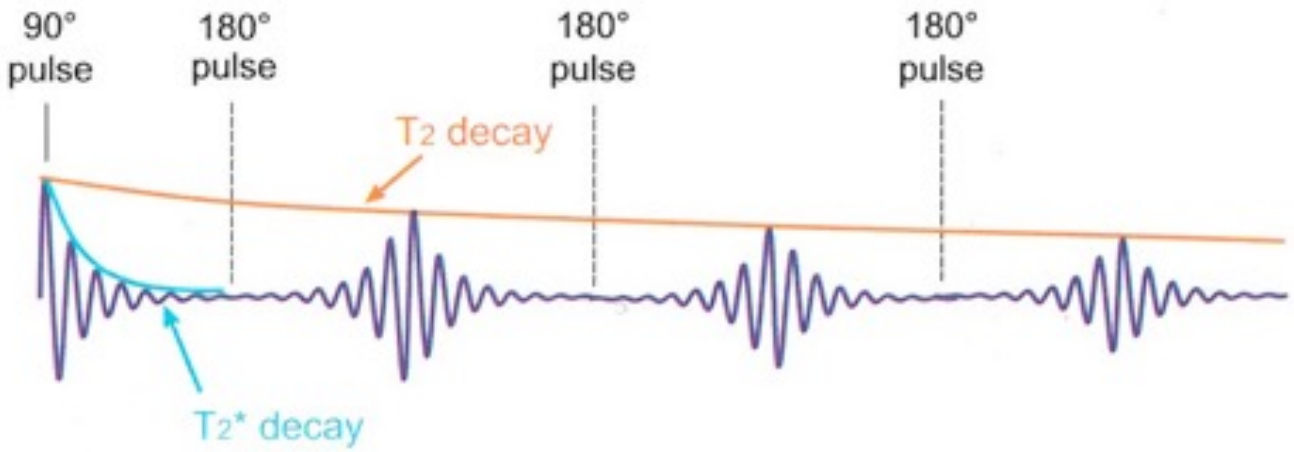
$$S \propto \rho_H \left[1 - e^{-TR/T1}\right] e^{-TE/T2}$$



■ FIGURE 12-22 The SE pulse sequence starts with a 90-degree pulse and produces an FID that decays according to T2* relaxation. After a delay time TE/2, a 180-degree RF pulse inverts the spins that re-establishes phase coherence and produces an echo at a time TE. Inhomogeneities of external magnetic fields are canceled, and the peak amplitude of the echo is determined by T2 decay. The rotating frame shows the evolution of the echo vector in the opposite direction of the FID. The sequence is repeated for each repetition period, TR.

Bushberg et al, The essential physics of medical imaging

T2-spin echo decay

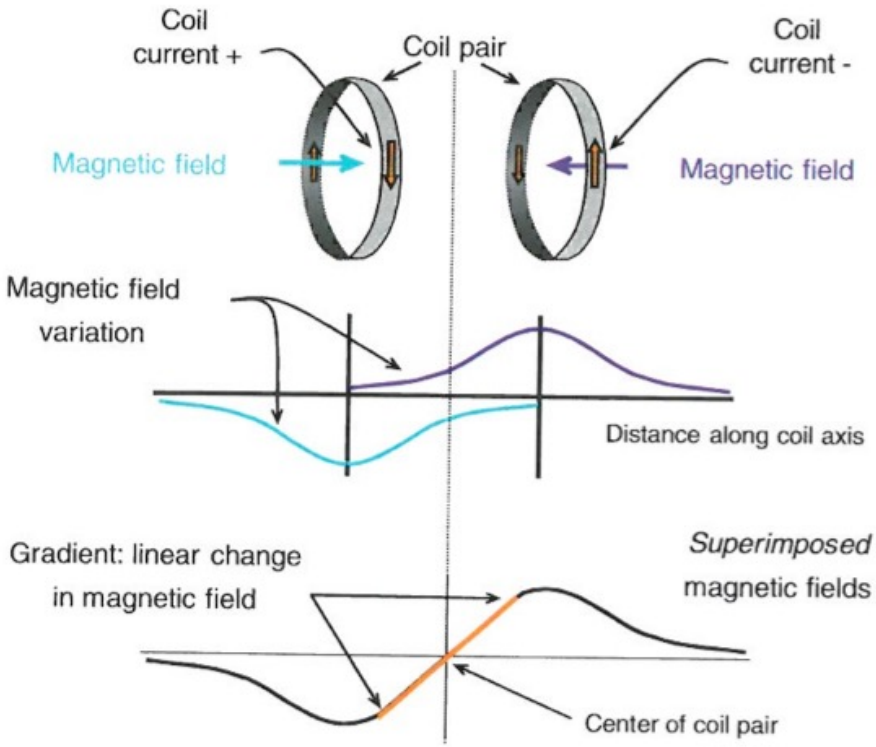


■ FIGURE 12-23 "True" T2 decay is determined from multiple 180-degree refocusing pulses acquired during the repetition period. While the FID envelope decays with the T2* decay constant, the peak amplitudes of subsequent echoes decay exponentially according to the T2 decay constant, as extrinsic magnetic field inhomogeneities are cancelled.

Bushberg et al, The essential physics of medical imaging



Gradients



■ FIGURE 12-4 Gradients are produced inside the main magnet with coil pairs. Individual conducting wire coils are separately energized with currents of opposite direction to produce magnetic fields of opposite polarity. Magnetic field strength decreases with distance from the center of each coil. When combined, the magnetic field variations form a linear change between the coils, producing a linear magnetic field gradient, as shown in the lower graph.

Bushberg et al, The essential physics of medical imaging

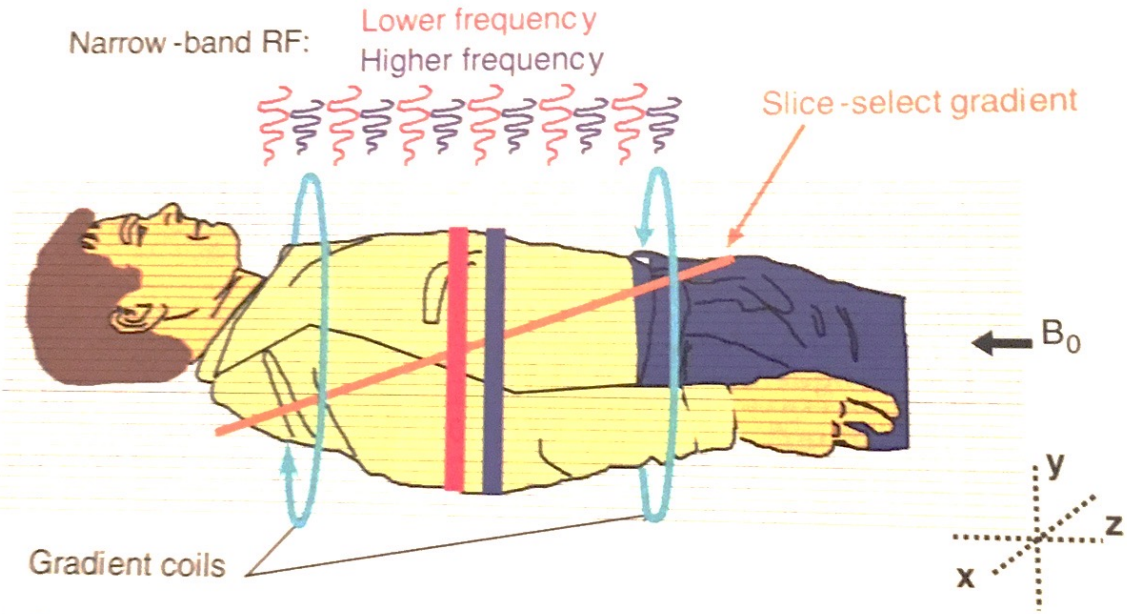
Image construction



Slice select gradient (SSG)

Proton precessional frequencies is increased or decreased dependent on their distance from null

Only protons with precessional frequencies matching RF frequencies will absorb energy = thin slice

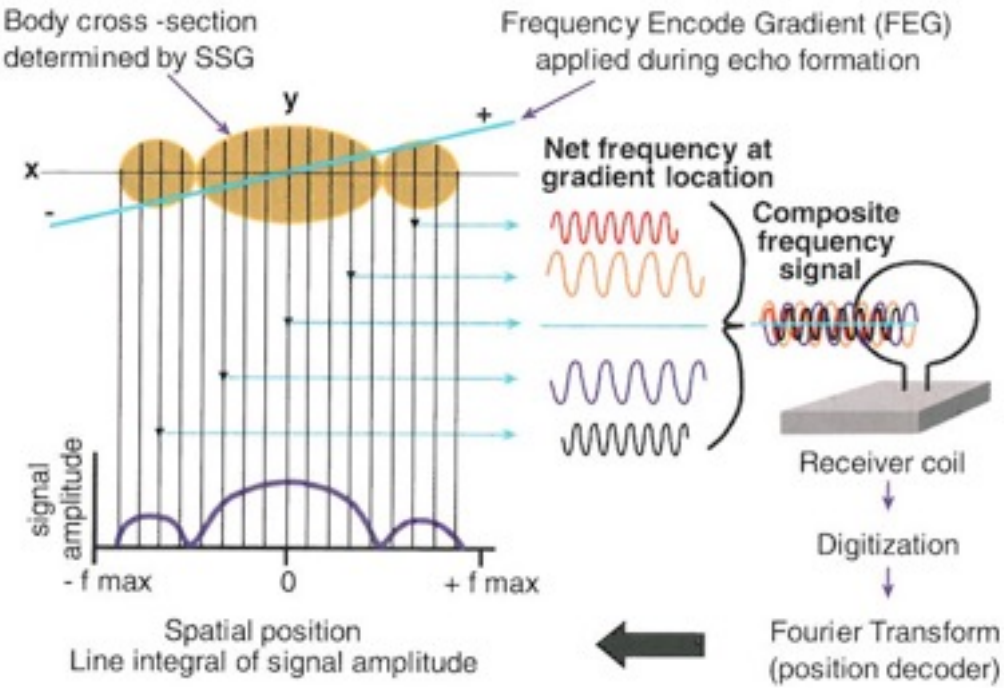


■ FIGURE 12-49 The SSG disperses the precessional frequencies of the protons in a known way along the gradient. A narrow band RF pulse excites only a selected volume (slice) of tissues, determined by frequency, BW, and SSG strength. In the example above, two narrow-band RF pulses with different center frequencies irradiate the whole body during the application of the gradient, and only those protons at the same frequencies as the RF pulses will absorb energy. Note that the higher frequency slice is shifted towards the positive pole of the applied gradient.



Frequency encode gradient

Frequency encode gradient = readout gradient, perpendicular to SSG



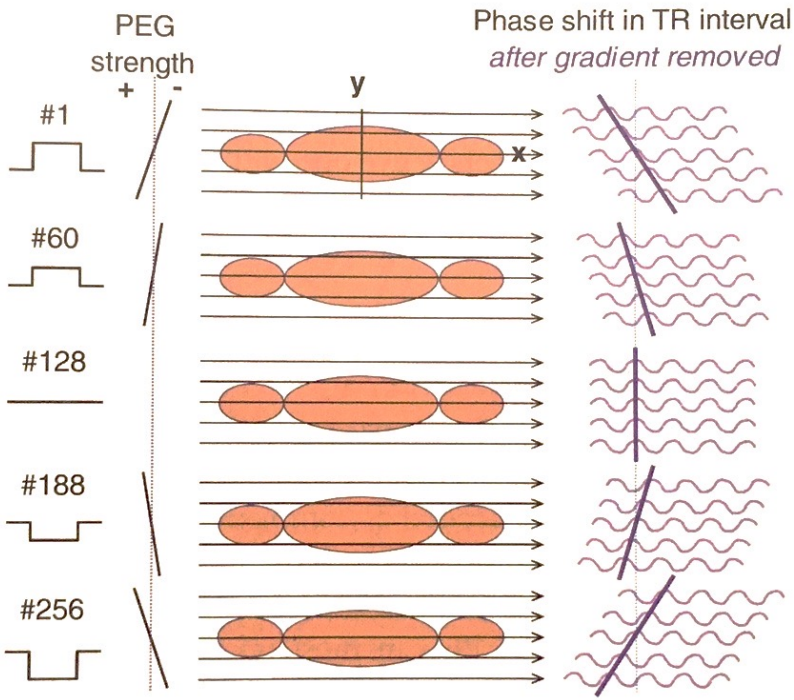
■ FIGURE 12-52 The *FEG* is applied in an orthogonal direction to the SSG, and confers *a spatially dependent variation* in the precessional frequencies of the protons. Acting only on those protons in a slice determined by the SSG excitation, the composite signal is acquired, digitized, demodulated (Larmor frequency removed), and Fourier transformed into frequency and amplitude information. A one-dimensional array represents a *projection* of the slice of tissue (amplitude and position) at a specific angle. (Demodulation into net frequencies occurs *after* detection by the receiver coil; this is shown in the figure for clarity only.)

Bushberg et al, The essential physics of medical imaging



Phase encode gradient (PEG)

Proton position in the third orthogonal dimension is determined with PEG. Introduce a phase change with a short duration PEG

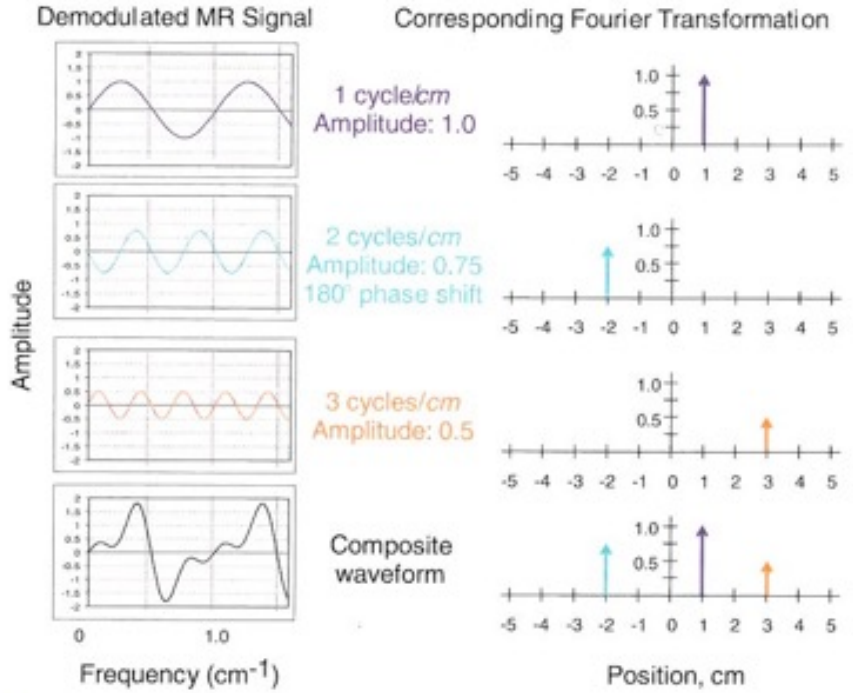


■ **FIGURE 12-55** The PEG is applied *before* the FEG and *after* the SSG. The PEG produces a spatially dependent variation in angular frequency of the excited spins for a brief duration, and generates a spatially dependent variation in phase when the spins return to the Larmor frequency. Incremental changes in the PEG strength for each TR interval spatially encodes the phase variations: protons at the null of the PEG do not experience any phase change, while protons in the periphery experience a large phase change dependent on their distance from the null. The incremental variation of the PEG strength can be thought of as providing specific "views" of the volume because the SSG and FEG remain fixed throughout the acquisition.

Bushberg et al, The essential physics of medical imaging

A rotating FEG in the x-y plane will give the acquisition of individual projections as a function of angle.

Fourier transform of spatial freq. signals



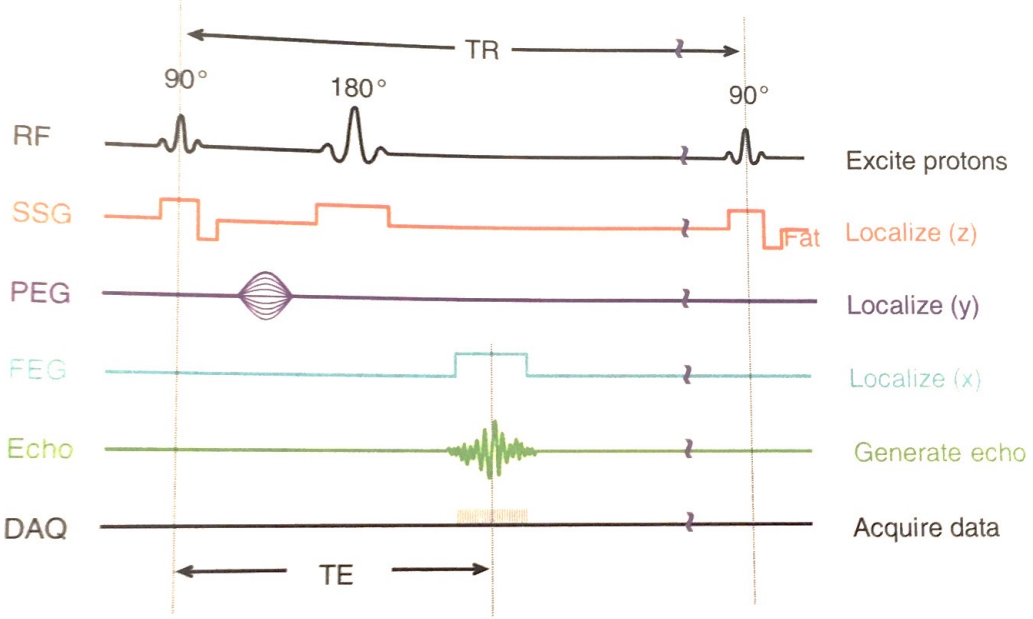
■ FIGURE 12-53 Spatial frequency signals (cycles/cm) and their Fourier transforms (spatial position) are shown for three simple sinusoidal waveforms with a specific amplitude and phase. The Fourier transform decodes the frequency, phase and amplitude variations in the spatial frequency domain into a corresponding position and amplitude in the spatial domain. A 180-degree phase shift (second from the top) is shifted in the negative direction from the origin. The composite waveform (a summation of all waveforms, lower left) is decoded by Fourier transformation into the corresponding positions and amplitudes (lower right).

Bushberg et al, The essential physics of medical imaging



All gradients (SSG + PEG + FEG)

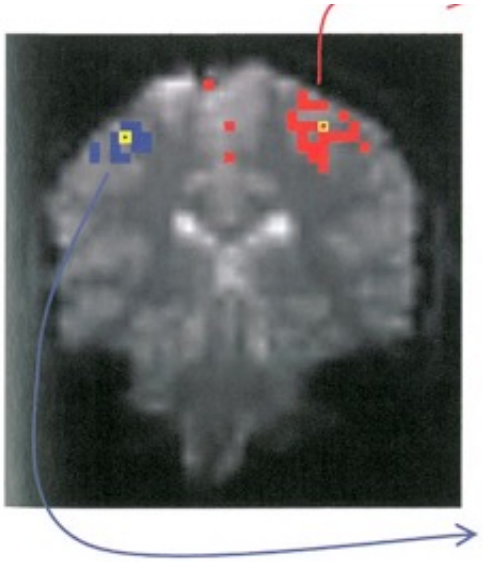
Proton position in the third orthogonal dimension is determined with PEG. Introduce a phase change with a short duration PEG



■ **FIGURE 12-56** A typical spin-echo pulse sequence diagram indicates the timing of the SSG, PEG, and FEG during the repetition time (TR) interval, synchronized with the RF pulses and the DAQ when the echo appears. Each TR interval is repeated with a different PEG strength (this appears as multiple lines in the illustration, but only one PEG strength is applied per TR as indicated by the bold line in this figure).

Bushberg et al, The essential physics of medical imaging

Functional MRI



Hb differs in how it responds to the magnetic field, the deoxygenated Hb molecule is slightly more attracted to magnetic field.

In consequence, the magnetic field is distorted by causing the nuclei to loose magnetization faster in the *T2 decay = MR pulse sequences sensitive to *T2 will have more signals when the blood is oxygenated than for the deoxygenated blood.

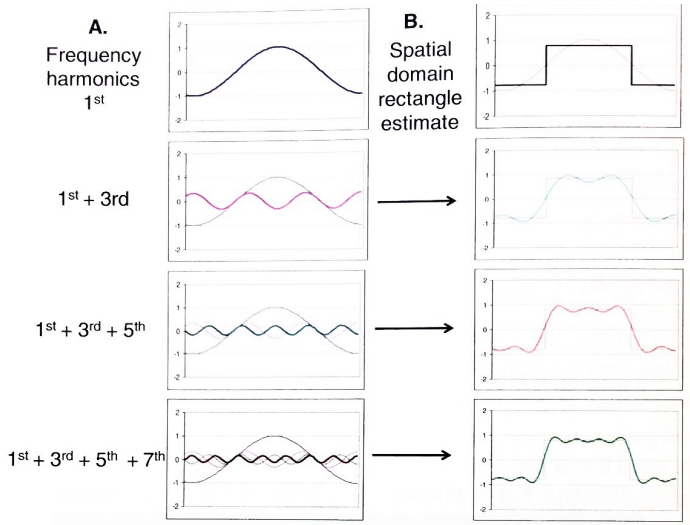
(The effect increases with the square of the magnetic field strength) = Minimum 1.5T

MRI-artefacts

Caused by insufficient sampling, could be reduced with a larger numb

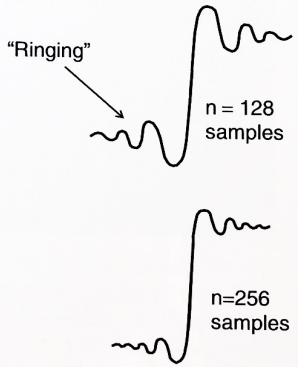


Ringing artefacts



■ **FIGURE 13-36** The synthesis of a spatial object occurs by the summation of frequency harmonics in the MR image. **A. Left column**: frequency harmonics that estimate a rectangle function with progressively higher frequencies and lower amplitudes are shown. **B. Middle column**: As higher frequency harmonics are included, the summed result more faithfully represents the object shape, in this example a rectangle with two vertical edges. The number of frequencies encoded in the MR image is dependent on the matrix size. **C. Right column**: A sharp transition boundary in an MR image is represented with 256 samples better than with128 samples (frequency harmonics in k-space). The amount of ringing caused by insufficient sampling is reduced with a larger number of samples.

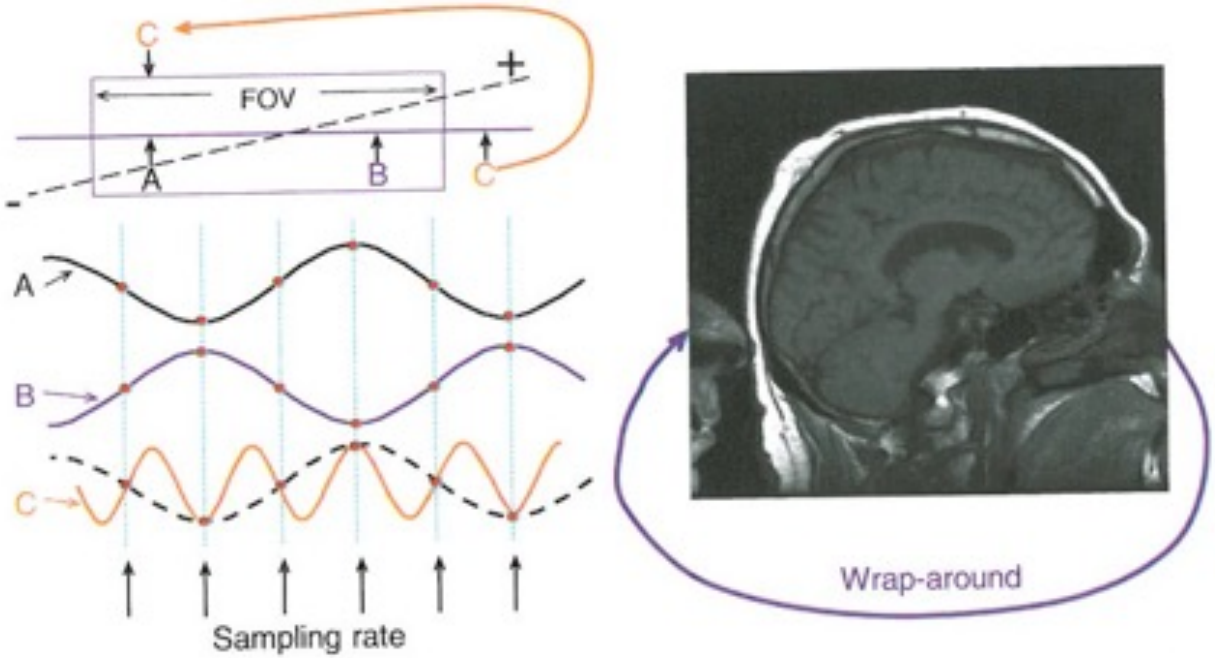
C. Sharp transition in MR image:



Bushberg et al, The essential physics of medical imaging



Wraparound artefacts



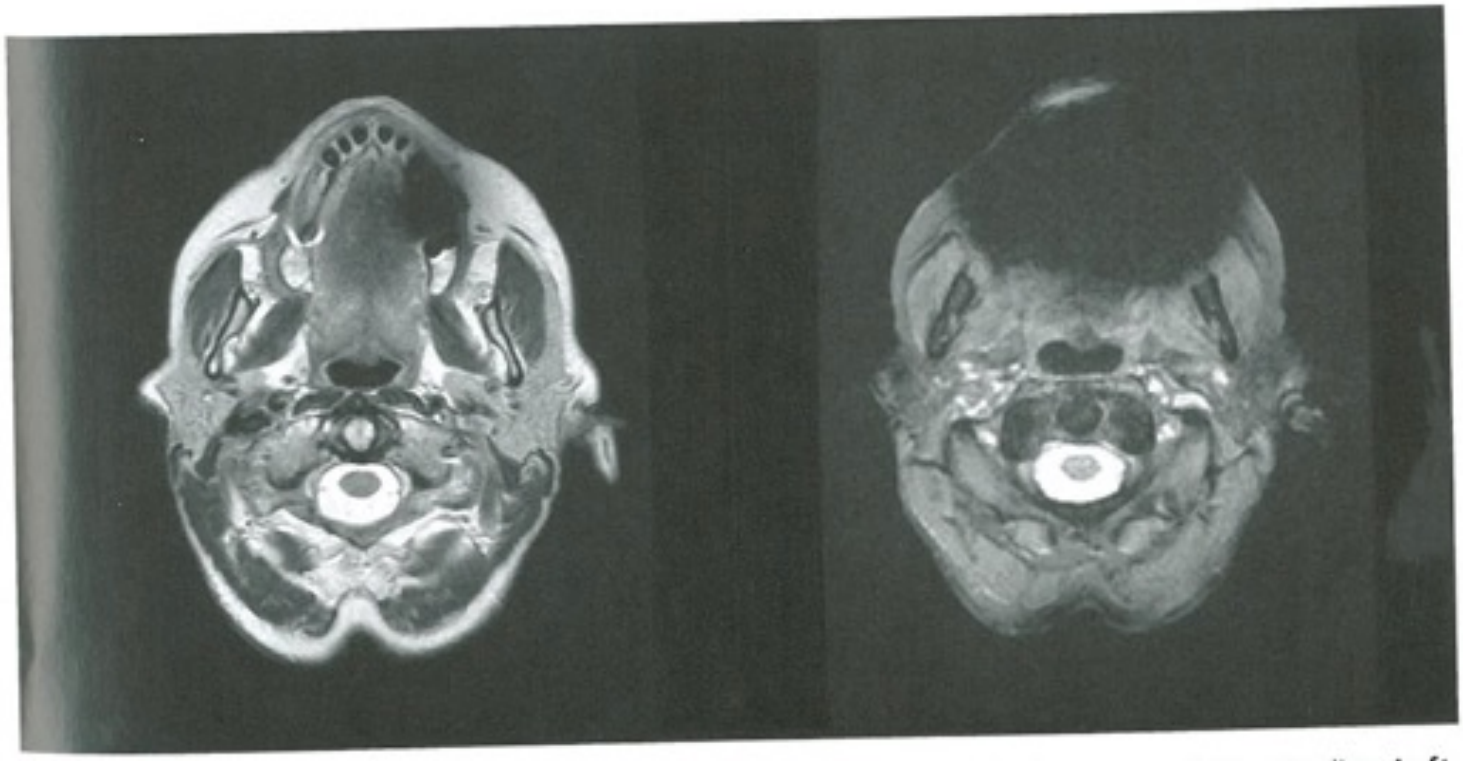
■ FIGURE 13-38 **Left.** Wraparound artifacts are caused by aliasing. Shown is a fixed sampling rate and net precessional frequencies occurring at position *A* and position *B* within the FOV that have identical frequencies but different phase. If signal from position *C* is at *twice* the frequency of *B* and insufficiently sampled, the same frequency and phase will be assigned to *C* as that assigned to *A*, and therefore will appear at that location. **Right.** A wrap-around artifact example displaces anatomy from one side of the image (or outside of the FOV) to the other side.

Bushberg et al, The essential physics of medical imaging

Susceptibility artefacts



Any drastic change in the magnetic susceptibility will distort the magnetic field. Changes in susceptiblity like tissue-air interface, or metals (ferrous or not) may have a significant effect on the local tissues adjacent to changes in susceptibility. Can also be helpful, like diagnosing the age of a hemorrhage based on signal characteristics of the blood degeneration products

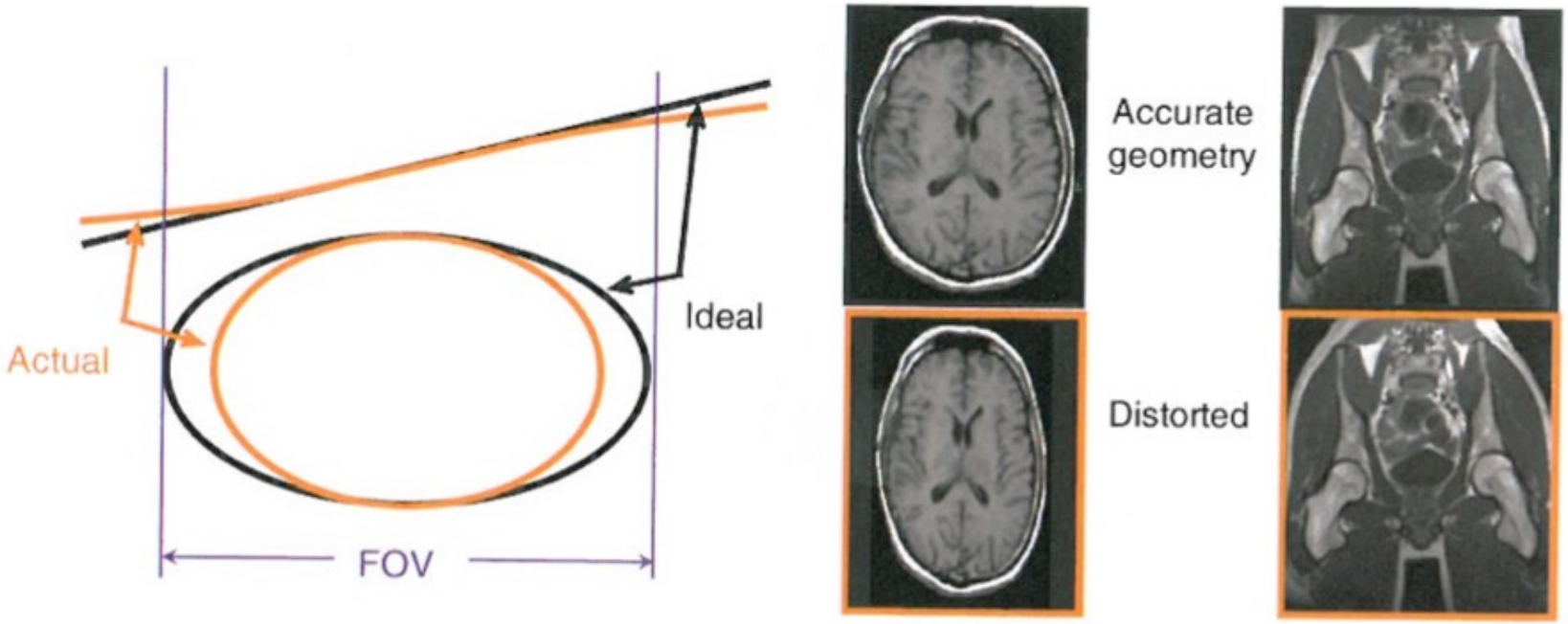


■ FIGURE 13-24 Susceptibility artifacts due to dental fillings are shown in the same axial image slice. **Left.** Axial T2-weighted fast spin echo image illustrates significant suppression of susceptibility artifacts with 180-degree refocusing pulse. **Right.** Axial T2*-weighted gradient echo image illustrates significant image void exacerbated by the gradient echo, where external inhomogeneities are not canceled in the reformed echo.

Bushberg et al, The essential physics of medical imaging



Gradient nonlinearity artefacts



■ **FIGURE 13-25** Gradient nonlinearity causes image distortions by mis-mapping anatomy. In the above examples, the strength of the gradient at the periphery is less than the ideal (*orange line* versus *black line*). This results in a compression of the imaged anatomy, with inaccurate geometry (images with *orange* border). For comparison, images acquired with linear corrections are shown above.

Any deviation or temporal instability in linear gradients will give a distortion. With gradient calibration and limitation of FOV (Lowering gradient field strength) or holding the gradient field strength and number of samples constant while decreasing the frequency bandwidth, minimize spatial distortion

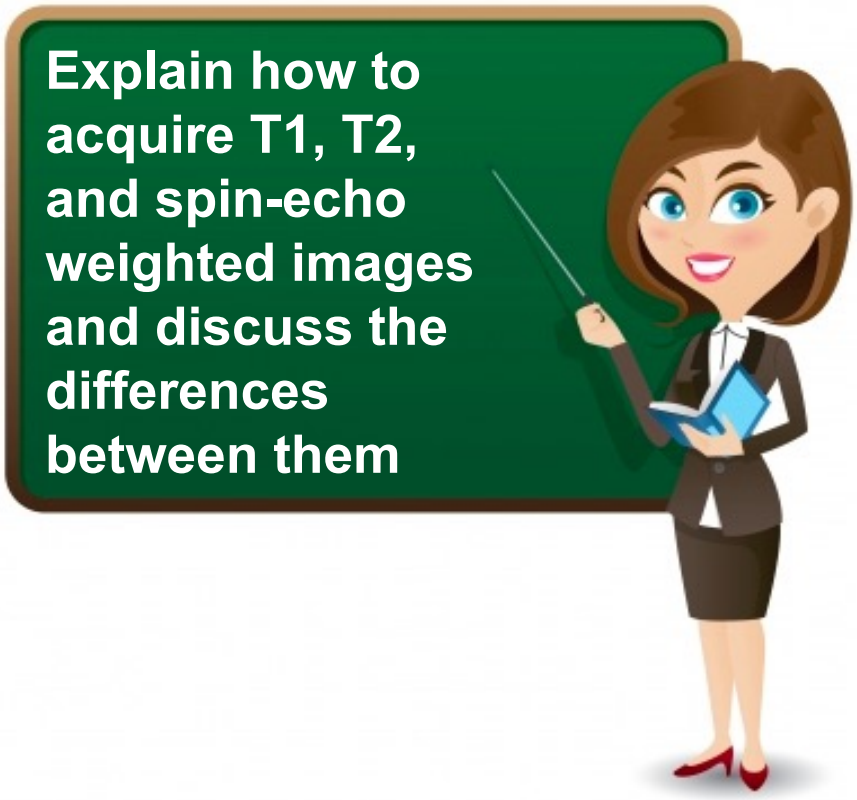


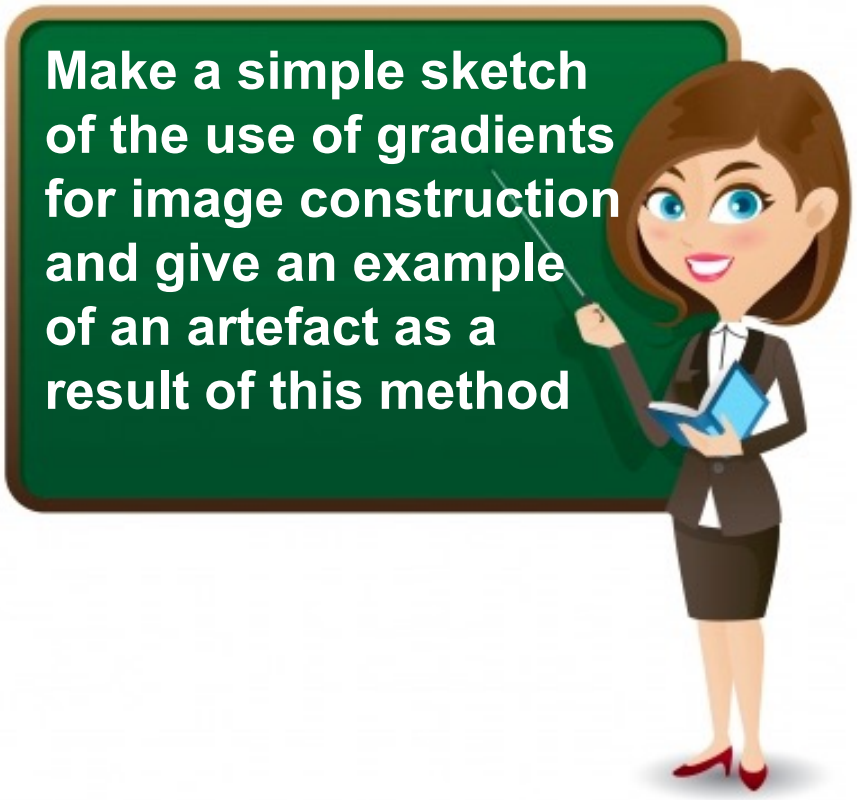
Adv/disadv MRI

- Advantages
- No harmful radiation
- Soft tissue imaging
- High resolution images of T1 or T2 preferences

- Disadvantages
- Expensive, large installation with superconducting magnets++
- Very strong magnetic field
- Claustrophobic
- Not for frozen tissue
- Time consuming

Exercise examples





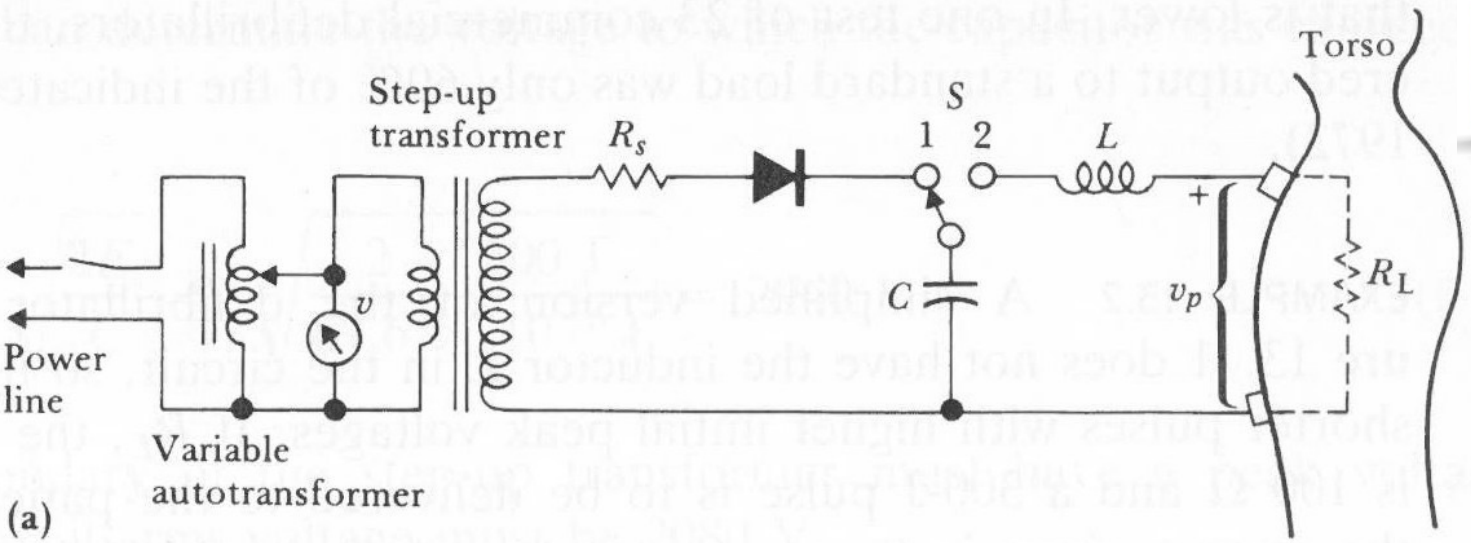


UiO : Department of Physics
University of Oslo

FYS 4250

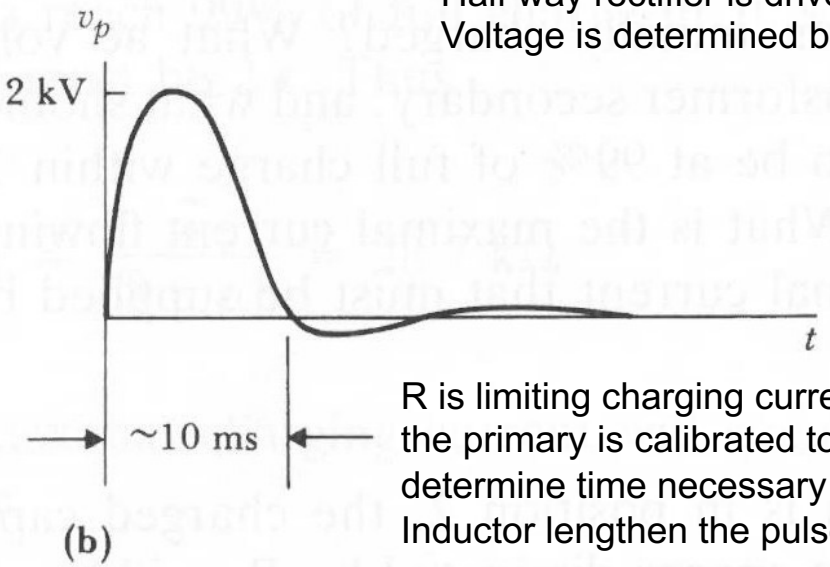
Lecture 15





Half way rectifier is driven by a step-up transformer to charge capacitor C. Voltage is determined by a variable autotransformator in the primary circuit

Apparatus



R is limiting charging current to protect circuit components, an AC voltmeter across the primary is calibrated to indicate energy stored in the capacitor. (Also helps to determine time necessary to achieve full charge on capacitor.).
Inductor lengthen the pulse, producing a waveshape.

Figure 13.11 (a) Basic circuit diagram for a capacitive-discharge type of cardiac defibrillator. (b) A typical waveform of the discharge pulse. The actual waveshape is strongly dependent on the values of L, C, and the torso resistance R_L.

Gamma Camera

- A camera for nuclear imaging. The most used so far was invented by H. Anger in the 1960's (The Anger camera)



http://img.medicalexpo.com/images_me/photo-g/70717-3803791.jpg

Principle: The patients drinks a cocktail including a radioactive tracer bound to a sugarlike molecule. Cells with high consumption of energy (e.g. Cancerous cells) will take up more of the tracer than healthy tissue, this can be measured with a gamma camera

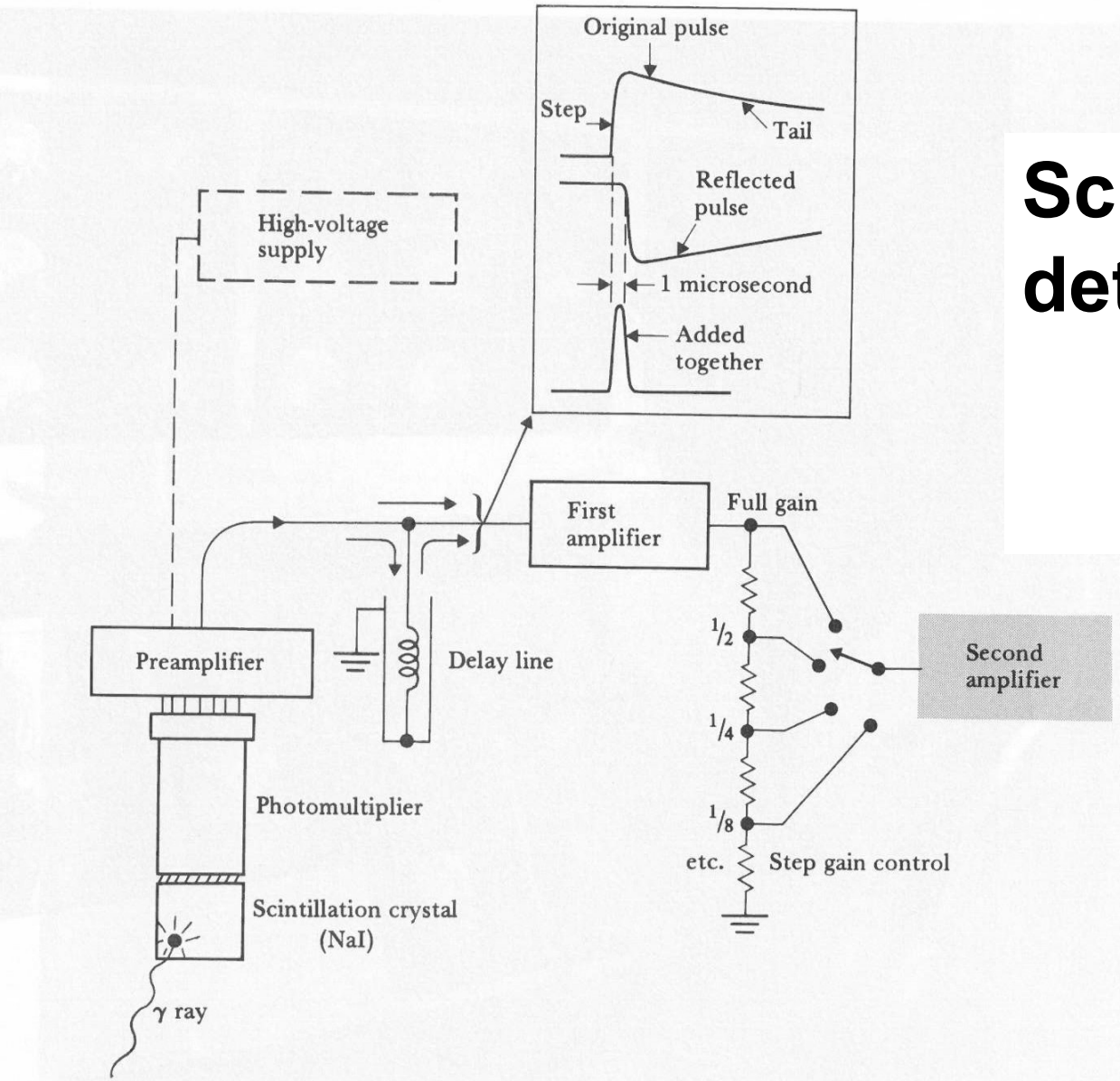
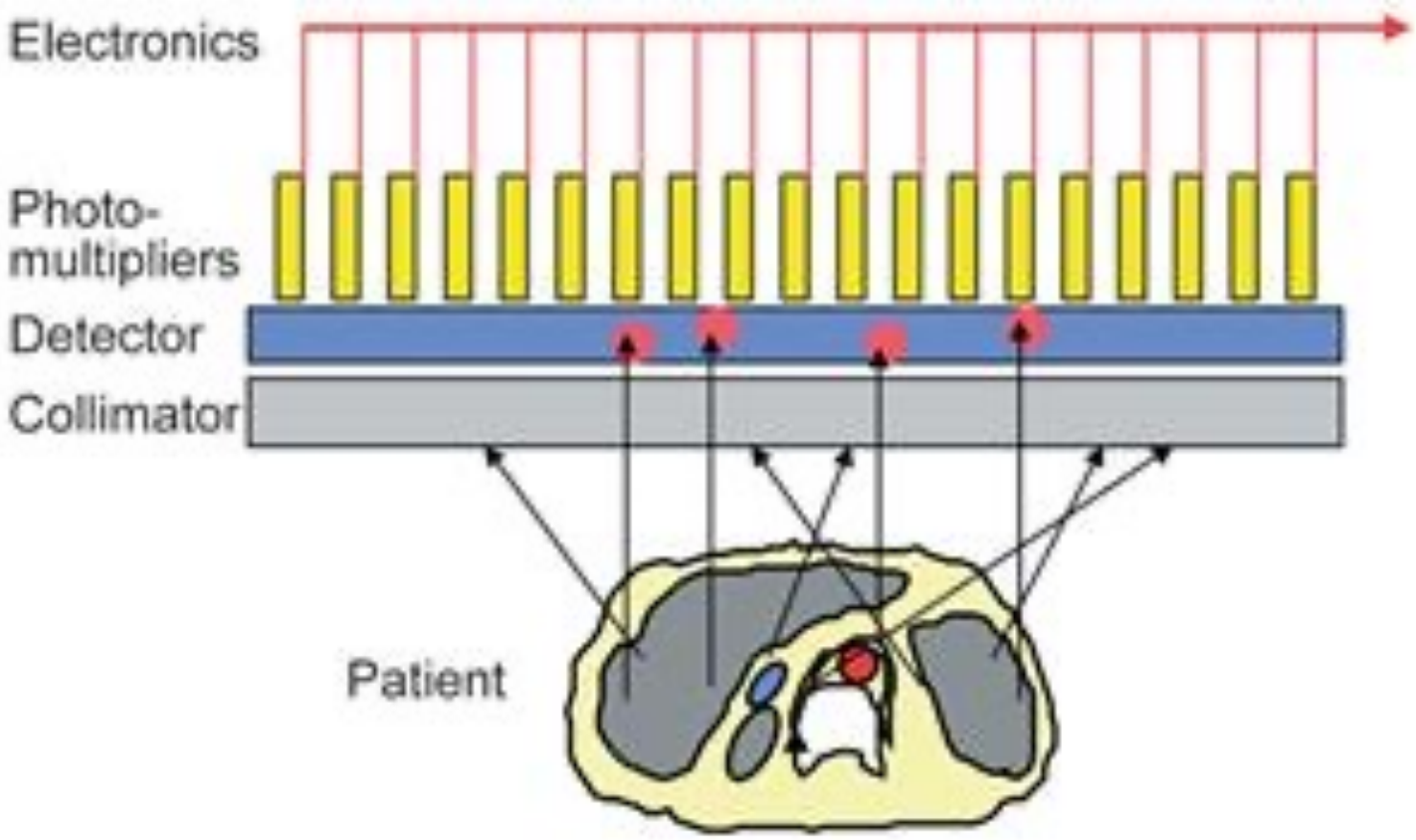


Figure 12.23 Basic implementation of a NaI scintillation detector, showing the scintillator, light-sensitive photomultiplier tube, and support electronics. (From H. N. Wagner, Jr., ed., *Principles of Nuclear Medicine*. Philadelphia: Saunders, 1968. Used with permission of W. B. Saunders Co.)

Scintillation-detector

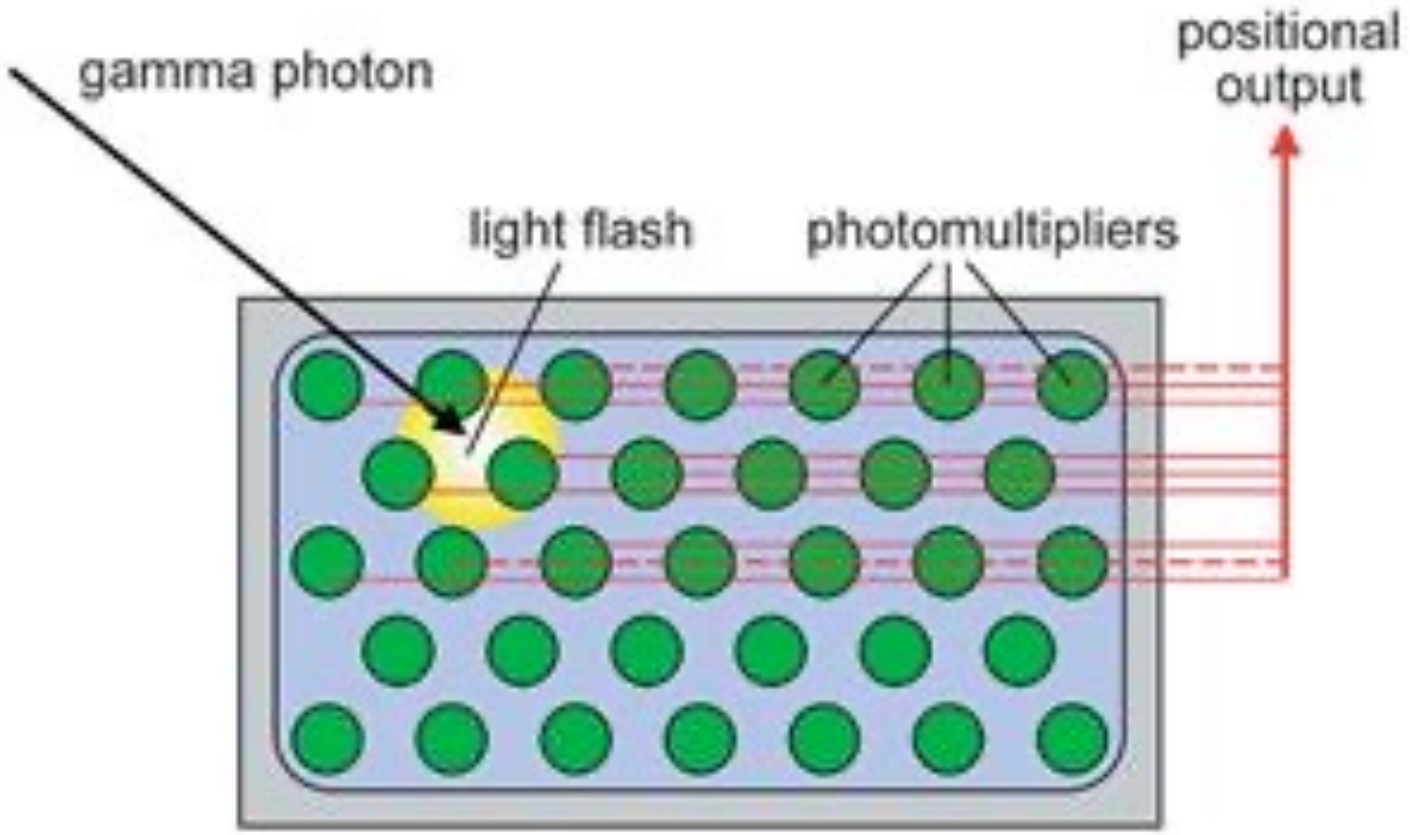


Anger camera



Photons with a proper direction are let through the collimator, into the detector and photomultipliers

Anger Camera (cont.)



SPECT- imaging

Single photon emission computer tomography, systematic use of gamma camera

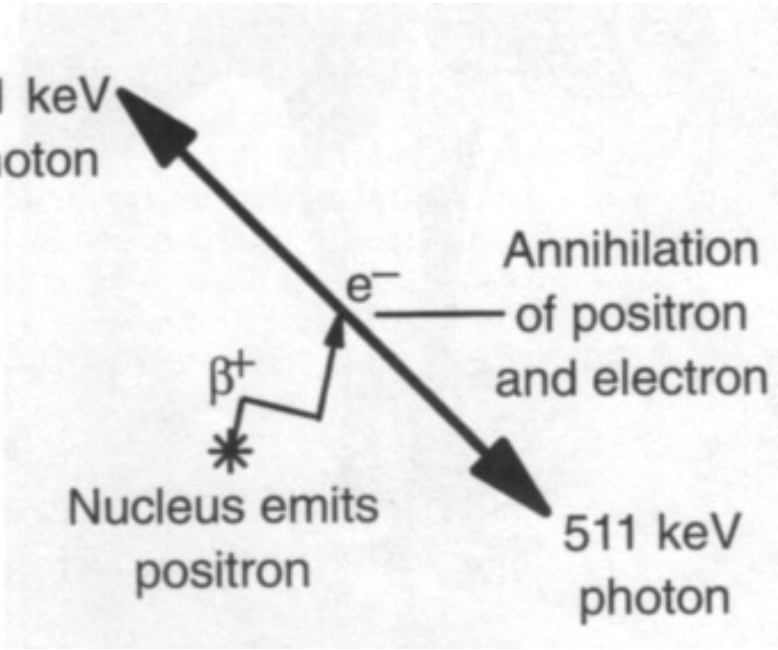


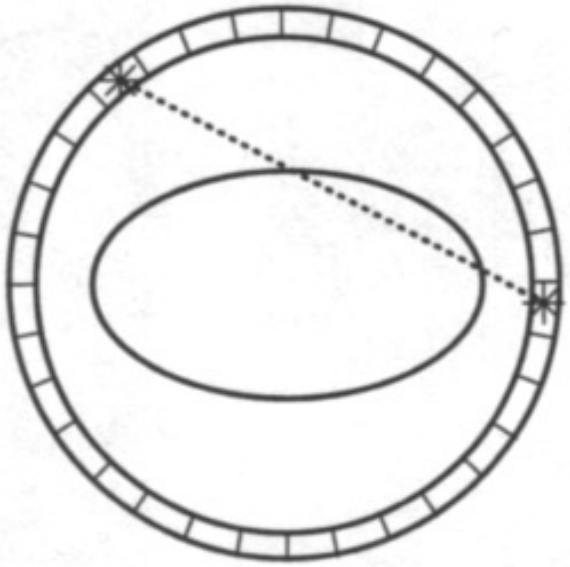
Image: GE Healtcare

PET/CT scanners



Image: http://2nznub4x5d61ra4q12fyu67t.wpengine.netdna-cdn.com/img/4363ct1.jpg


511 keV
photon
e⁻
Annihilation
of positron
and electron
β+
Nucleus emits
positron
511 keV
photon

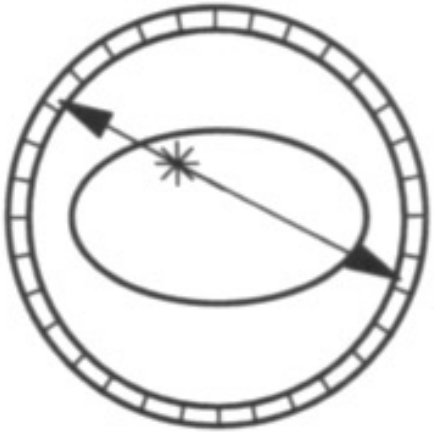


True, random, and scatter coincidences

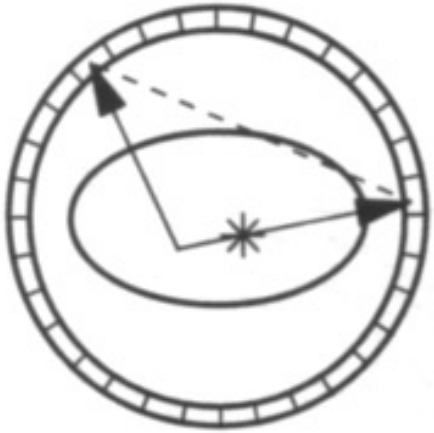
- A *true coincidence* = detection is the result of a single nuclear annihilation
- A *random coincidence* = photons from different nuclear transformations are detected simultaneously at the detectors. May give erroneous results.
- A *scatter coincidence* = one or both photons from a single annihilation are scattered in different directions but still detected in the detector



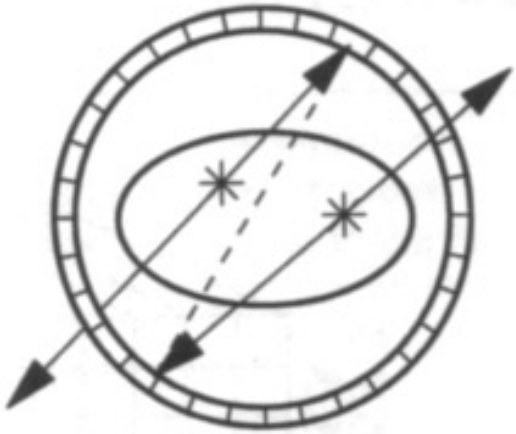
True



Scattered

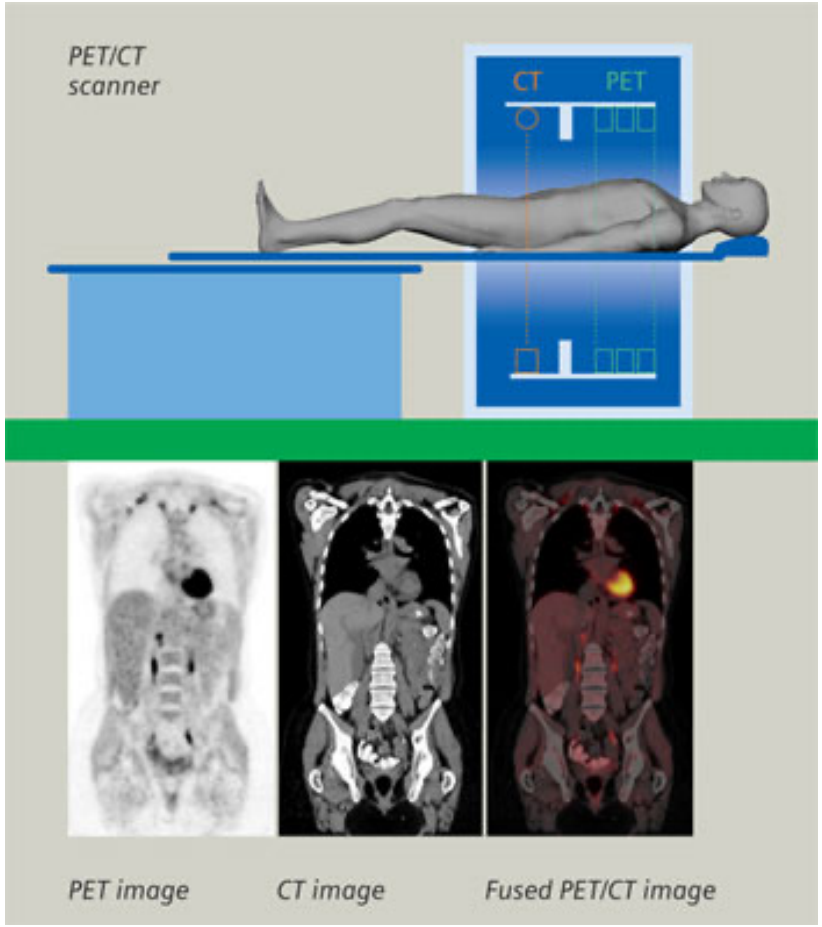


Random

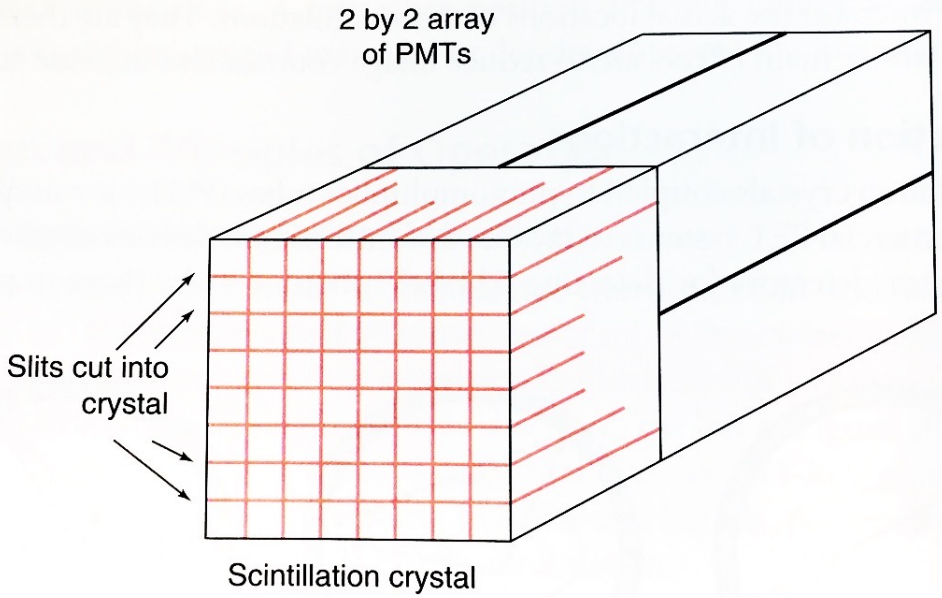


PET-CT

- Usually combined with CT in order to localize activity in the body



Scintillation crystals and photomultiplier tubes

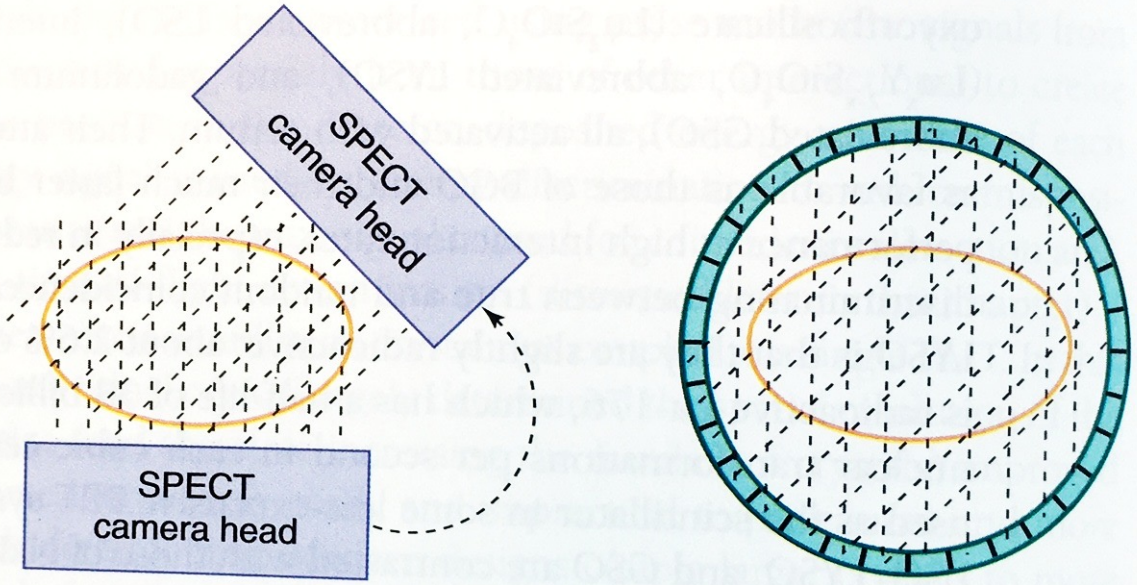


■ **FIGURE 19-17** A technique for coupling scintillation crystals to photomultiplier tubes (PMTs). The relative heights of the pulses from the four PMTs are used to determine the position of each interaction in the crystal. The thick (2 to 3 cm) crystal is necessary to provide a reasonable detection efficiency for the 511-keV annihilation photons. The slits cut in the scintillation crystal form light pipes, limiting the spread of light from interactions in the front portion of the crystal, which otherwise would reduce the spatial resolution. This design permits four PMTs to serve 64 detector elements.

Source: Bushberg et al. The essential physics of Medical Imaging (2012)

SPECT vs PET scanner systems

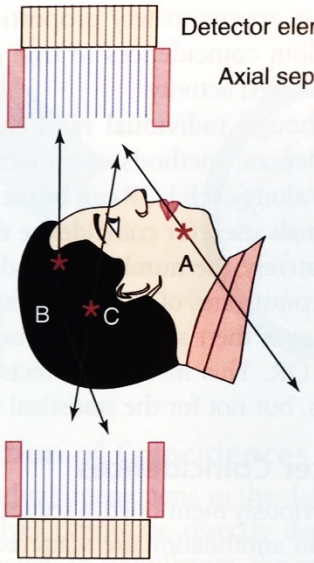
■ **FIGURE 19-18** Acquisition of projection data by a SPECT system (**left**) and a PET system (**right**), showing how each system collects data for two projections. However, the PET system collects data for all projections simultaneously, whereas the scintillation camera head of the SPECT system must move to collect data from each projection angle.



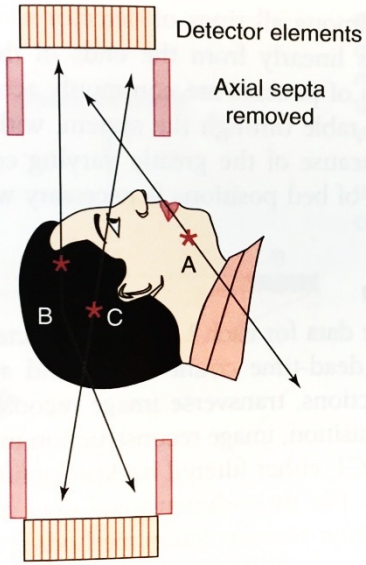
Source: Bushberg et al. The essential physics of Medical Imaging (2012)
Source: Bushberg et al. The essential physics of Medical Imaging (2012)



2D vs 3D PET scanner



■ FIGURE 19-19 Side view of PET scanner illustrating two-dimensional data acquisition. The axial septa prevent photons from activity outside the field-of-view (**A**) and most scattered photons (**B**) from causing counts in the detectors. However, many valid photon pairs (**C**) are also absorbed.



■ FIGURE 19-21 Side view of PET scanner illustrating three-dimensional data acquisition. Without axial septa, interactions from activity outside the FOV (**A**) and scattered photons (**B**) are greatly increased, increasing the dead time, random coincidence fraction, and scatter coincidence fraction. However, the number of true coincidences (**C**) detected is also greatly increased.

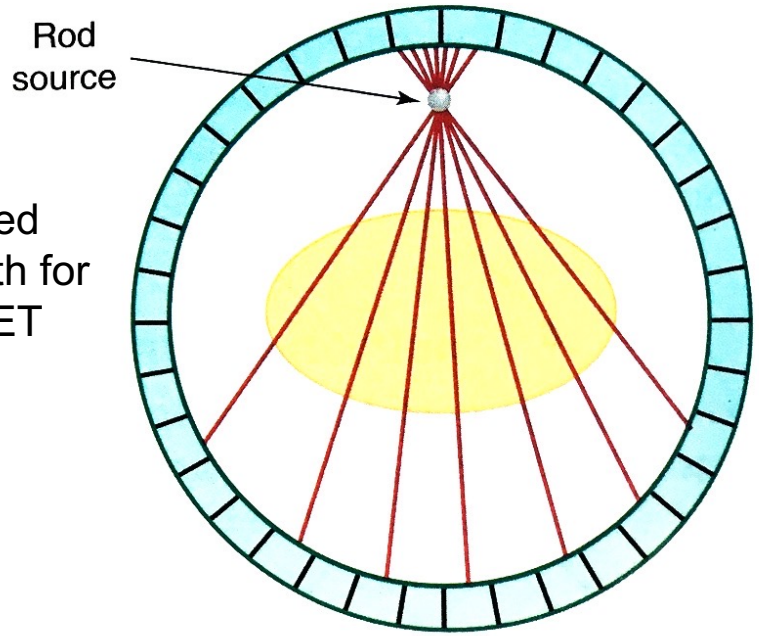
Source: Bushberg et al. The essential physics of Medical Imaging (2012)



Some of the photons are lost on the way to the detectors, this is depending on the tissue they are penetrating. How can we correct for this?

Attenuation correction

■ **FIGURE 19-26** Rod source for attenuation correction in a dedicated PET system.



Attenuation coefficient for 511-keV annihilation photons in soft tissue is lower than photons emitted by most radionuclides, but the average path length for both to escape is much longer = Higher loss in PET

LOR = Line of radiation

Disadvantages – Increased imaging time
-Slightly increased dose
-Increased spatial noise
-Patient movement can give spatial misregistration between attenuation map and emission data when not aquired simultaneously

Today, CT is used for attenuation correction

Source: Bushberg et al. The essential physics of Medical Imaging (2012)

Comparison of SPECT and PET



Source: Bushberg et al. The essential physics of Medical Imaging (

TABLE 19-5 COMPARISON OF SPECT AND PET

	SPECT	PET
Principle of projection data collection	Collimation.	Annihilation coincidence detection (ACD).
Transverse image reconstruction	Iterative methods or filtered backprojection.	Iterative methods or filtered backprojection.
Radionuclides	Any emitting x rays, gamma rays, or annihilation photons. Optimal performance for photon energies of 100–200 keV.	Positron emitters only.
Spatial resolution	Depends upon collimator and camera orbit. Within a transaxial image, the resolution in the radial direction is relatively uniform, but the tangential resolution is degraded toward the center. Typically about 10 mm FWHM at center for a 30 cm diameter orbit and ^{99m}Tc. Larger camera orbits produce worse resolution.	Relatively constant across transaxial image, best at center. Typically 4.5–5 mm FWHM at center.
Attenuation	Attenuation less severe. Radioactive attenuation correction sources or x-ray CT can correct for attenuation.	Attenuation more severe. Radioactive attenuation correction sources or x-ray CT can correct for attenuation.

UiO : Department of Physics
University of Oslo

PET-MRI



Disadvantages with PET-CT

a. High dose
b. Sequential (no simultaneous acquistion)

Advantages with PET-MR

a. No extra dose
b. Soft tissue imaging
c. Functional imaging

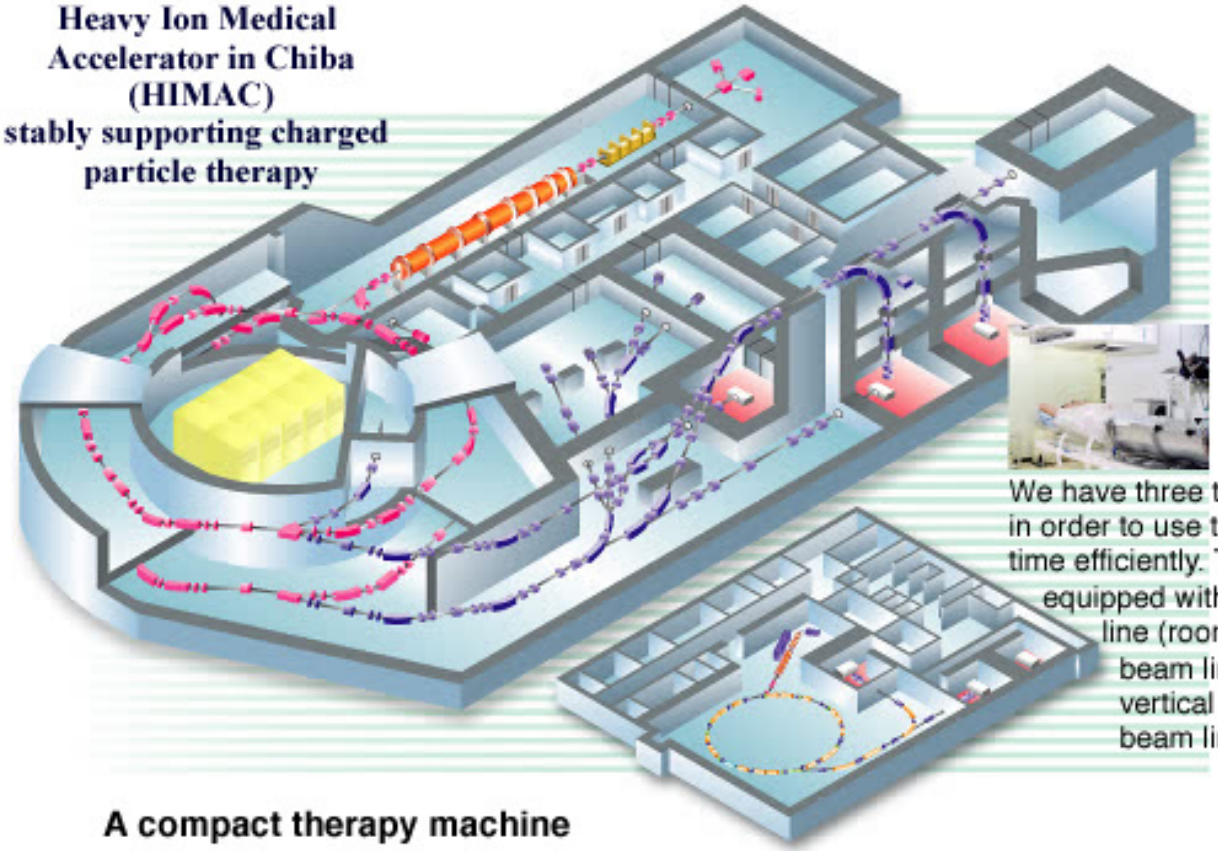
Main problem with PET-MR: Photomultiplier tubes in the PET are sensitive to magnetic fields

Solution:

a. Two scanners in series
b. Integration of PET-hardware into the MRI-gantry

Non-invasive surgery

Heavy Ion Medical Accelerator in Chiba (HIMAC) stably supporting charged particle therapy



We have three treatment rooms in order to use the HIMAC beam time efficiently. These rooms are equipped with a vertical beam line (room A), a horizontal beam line (room C) and vertical and horizontal beam lines (room B).

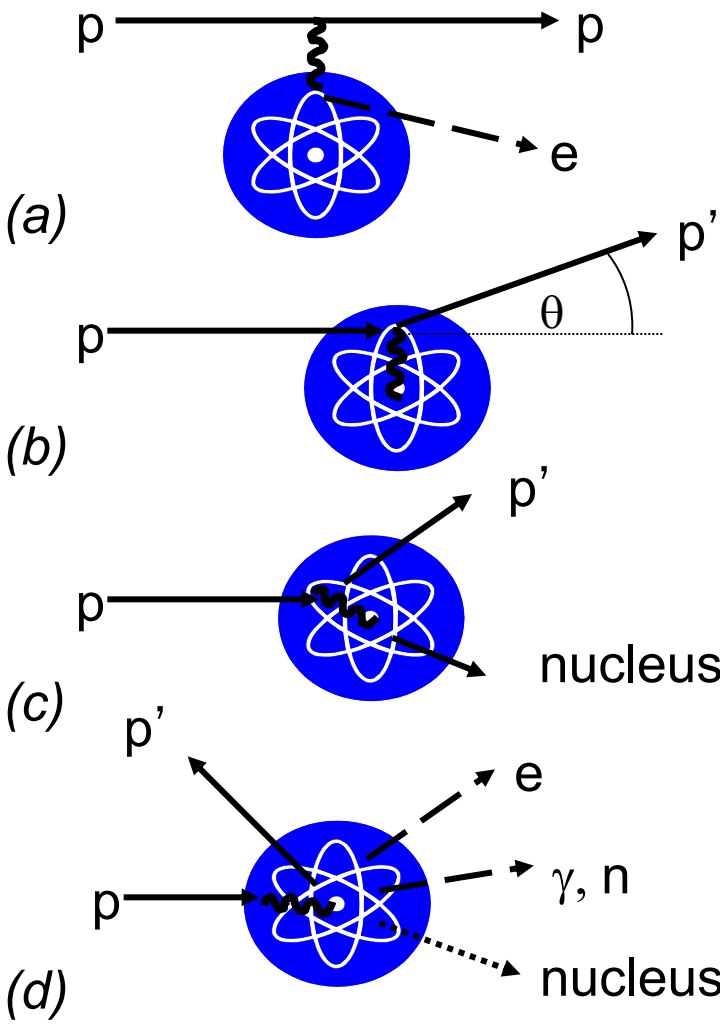
A compact therapy machine

The NIRS completed research and development on a compact carbon therapy machine in FY 2005. Gunma University has adopted our proposal and will start construction of a new therapy facility in FY 2006. The NIRS is giving technical support to this project at Gunma University.

Kilde: NIRS, Chiba, Japan

Proton interactions

- Electron interactions (*a*)
  - Ionization
  - Excitation
- Nuclear interactions (*b-d*)
  - Multiple Coulomb scattering (*b*), small q
  - Elastic nuclear collision (*c*), large q
  - Nonelastic nuclear interaction (*d*)





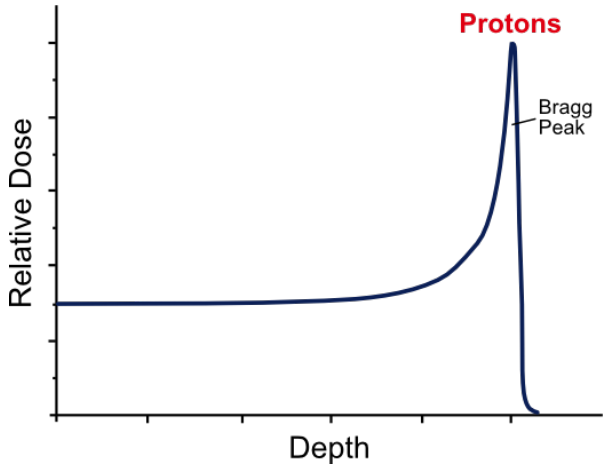
The Bragg Peak

- A moving particle will loose energy according to the Bethe Bloch formula

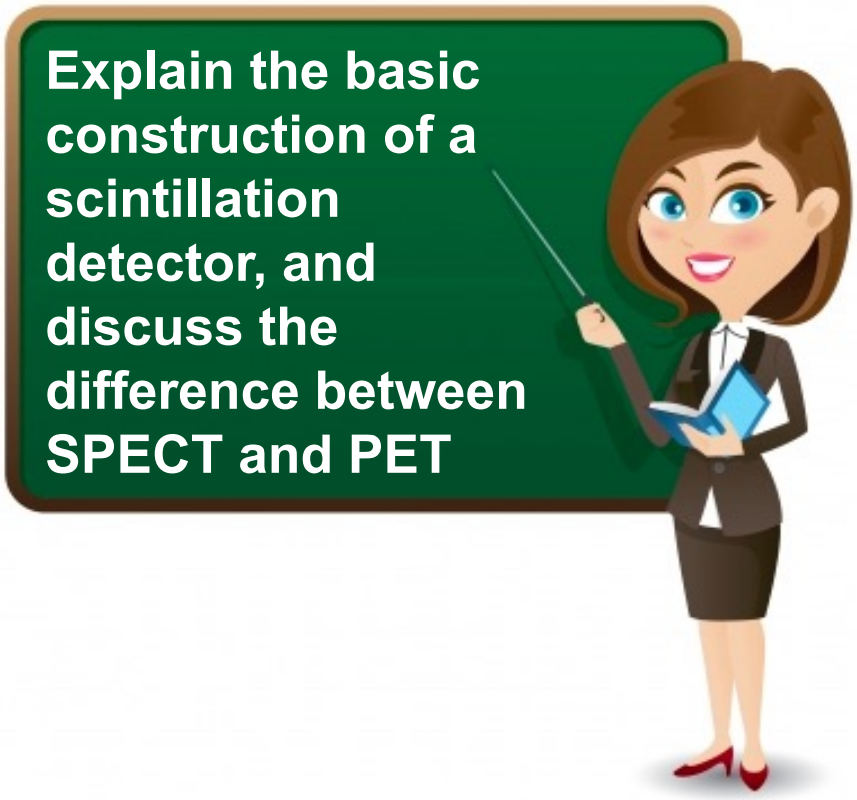
$$-\frac{\mathrm{d}E}{\mathrm{d}x} = \frac{4\pi n z^2}{m_e c^2 \beta^2} \cdot \left(\frac{e^2}{4\pi\epsilon_0}\right)^2 \cdot \left[\ln\left(\frac{2m_e c^2 \beta^2}{I \cdot (1-\beta^2)}\right) - \beta^2\right]$$

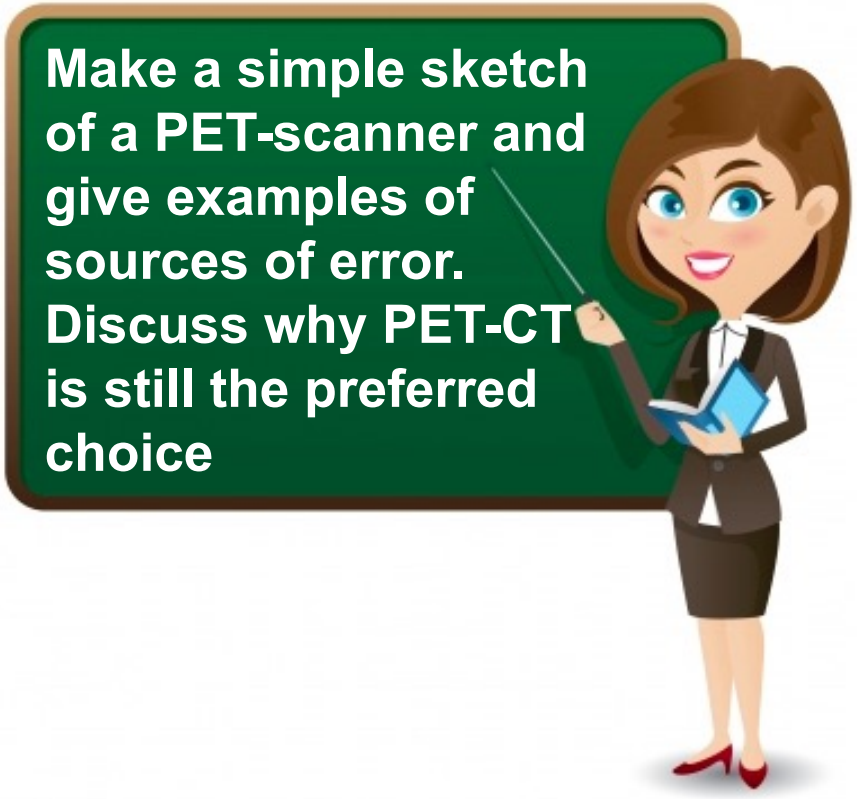
due to collisions with electrons of the absorber material. In addition there is a nuclear fragmentation reaction that gives very complex alterations of the particle field composition

- As energy decreases, the statistical probability of more nuclear interactions increase dramatically, and most of the energy is deposited shortly before the kinetic energy reach zero



Exercise examples





Finally.....

Slicky tricks

1. When preparing for your exam, don't get lost in details. Start with the main topics and be sure you understand them before you start to drill down in the substance
2. During the exam: Keep talking
3. If you have nothing more to say, try to direct the attention slightly to a related topic of your preferation
4. All amplifiers (more or less), in this course have the same demands: High input impedance, high CMRR, protection to the organism, high gain, easy to calibrate and good frequency characteristics within the physiological spectrum
5. The main goal of this course is to obtain a breadth of outlook in this complicated field, don't forget that. A typical question could be to compare different image modalities across all chapters.
6. If (on a direct question) you don't know the answer, try to talk around the question while closely observing the response from both the examinator and sensor. Very often, it is possible to discuss yourself towards the answer.
7. Don't exaggerate the consequence when you're in, this is no execution. Take your time, breath calmly and think before you speek and we will have a nice, peaceful conversation
8. Even if the curriculum for the exam is all of your textbook (except from chapter 9), the main focus comes from the lectures.

Good luck!

