Sound - Ultrasound

Ádám Orosz
Department of Biophysics and Radiation Biology
Semmelweis University

Outline of the lecture

Topics:

- **Sound as wave**
- **Propagation of sound in media**
- **Sensory perception of sound**
- **Audiometry**
- **Ultrasound and its applications**
- **Basics of sonography**
- **Ultrasound images**
- **Measurement of distance and flow velocity**

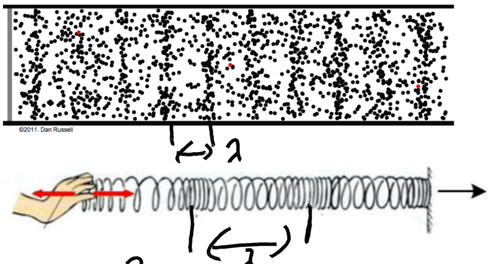
Textbook chapters: **II/2.4.; IV/3.1.; IV/3.5.; VIII/4.2.**

Related laboratory practices:
Ultrasound, Audiometry

Sound as wave

mechanical wave → medium

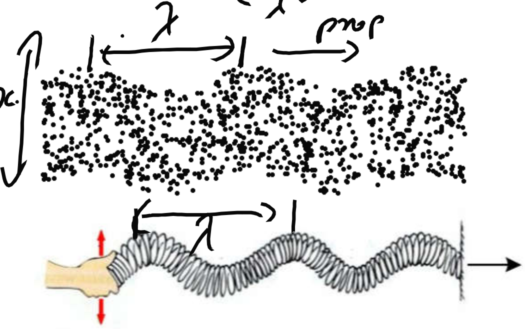
longitudinal wave (air, fluids)



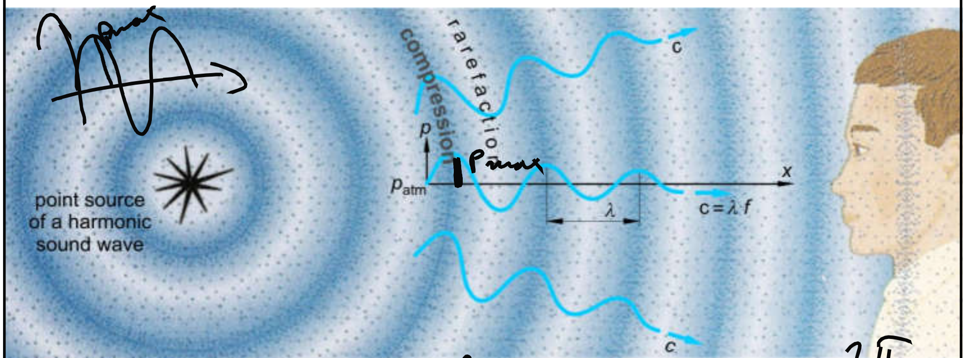
$$c = \frac{\lambda}{T} = \lambda \cdot f$$

~~dispersion~~

transverse wave (solids, fluid surface)



Sound – travelling of vibration state in time and space



$p_{sum} = p_{atm} + p_{sound}$

$y(t) = A \cdot \sin \omega T$

$p(t) = p_{max} \cdot \sin\left(\frac{2\pi}{T} \cdot t\right)$

$\varphi \sim \omega \cdot t \sim \frac{2\pi}{\lambda} \cdot x$ $\quad \omega = \frac{2\pi}{T}$

$p(x) = p_{max} \cdot \sin\left(\frac{2\pi}{\lambda} \cdot x\right)$

$p(t,x) = p_{max} \cdot \sin\left[2\pi\left(\frac{t}{T} - \frac{x}{\lambda}\right)\right]$

Propagation of sound in media

compressibility, density, speed

$$\frac{F}{A} = p \Rightarrow -\frac{\Delta V}{V}$$

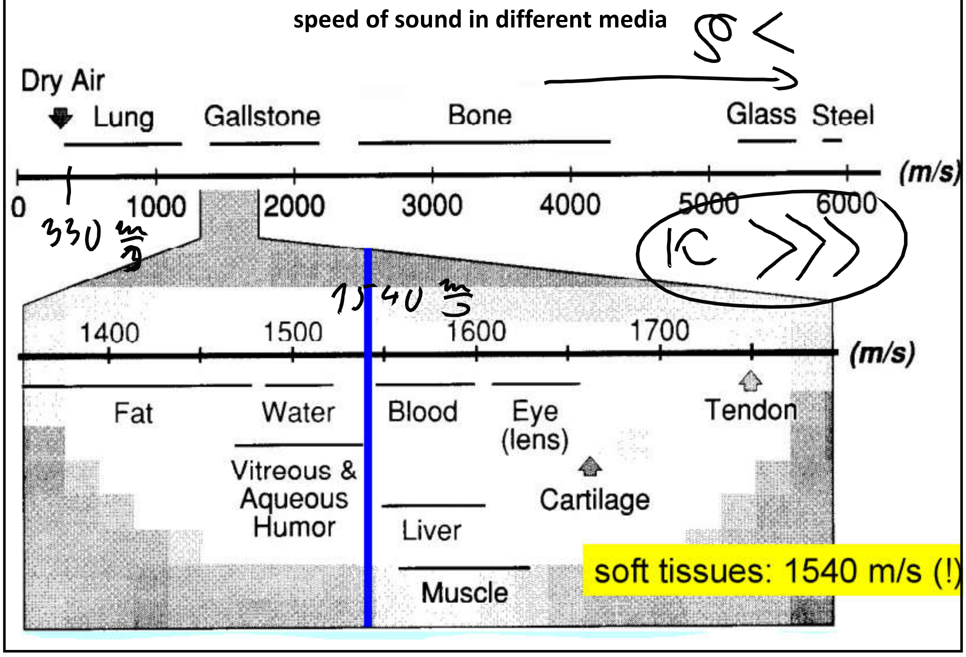
$$K = \frac{-\frac{\Delta V}{V}}{\Delta p} \quad \left[\frac{1}{Pa}\right]$$

$$c = \frac{1}{\sqrt{\rho \cdot K}} \quad \left[\frac{m}{s}\right]$$

$$c \sim \frac{1}{\rho}, \quad \sim \frac{1}{K}$$

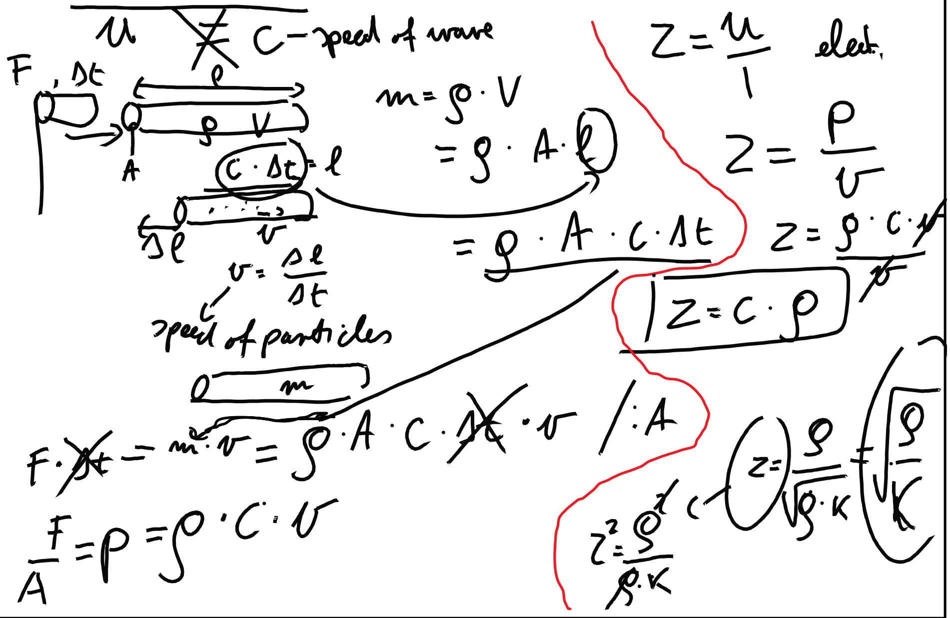
Propagation of sound in media

speed of sound in different media



Propagation of sound in media

velocity of praticles and pressure, acoustic impedance/hardness



Propagation of sound in media

examples - density, compressibility, speed, acoustic impedance

$$\kappa = \frac{-\Delta V / V}{\Delta p} \qquad c = \frac{1}{\sqrt{\rho\kappa}} \qquad Z = \rho c = \sqrt{\frac{\rho}{\kappa}}$$

material	ρ	κ	c	Z
	[kg/m^3]	[1/GPa]	[m/s]	[kg/(m^2·s)]
air	1.3	7650	331	0.00043·10^6
water, 20°C	998	0,45	1492	1.49·10^6
soft tissue	1060	0.40	1540	1.63·10^6
dense bone	1700	0.05	3600	6.12·10^6
quartz	2650	0.011	5736	15.2·10^6

Propagation of sound in media

intensity, intensity-level

$I = U \cdot U$

$P = \frac{U^2}{R}$

$P = \frac{U_{eff}^2}{Z}$

$J \sim A^2$

$$J = \frac{1}{Z}\Delta p_{eff}^{\ 2}$$

$J = \frac{\Delta P_{eff}^2}{Z}$

$$J_{dB} = 10\lg\frac{J}{J_0}$$

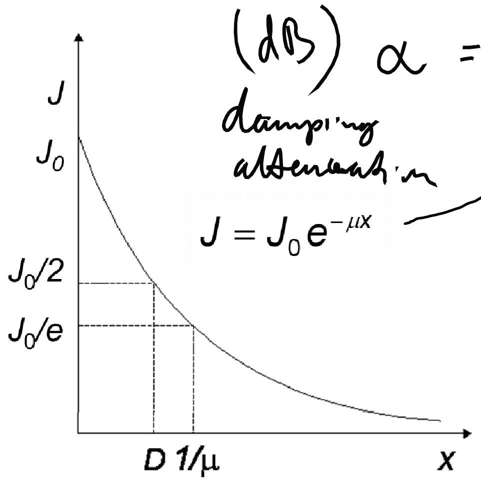
Propagation of sound in media

loss of energy during propagation, damping, specific damping

(dB) $\alpha = 10 \lg \frac{J_0}{J} = 10\, \mu \cdot x \cdot \lg e$

damping
attenuation

$\mu \sim \alpha \sim f$



$$J = J_0 e^{-\mu x}$$

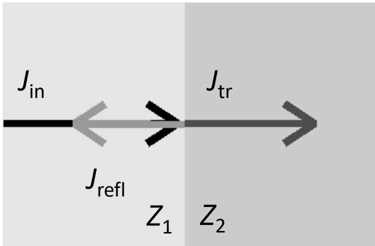
specific damping
material

$\frac{\alpha}{f \cdot X}$

f = 1 MHz-en:
D_{air} ~ 1 cm
D_{water} ~ 1 m

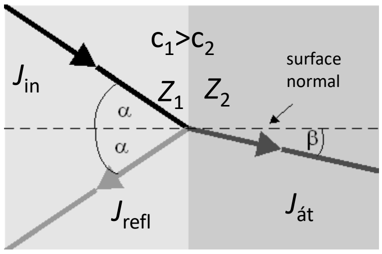
Phenomena at the boundary of media

normal incidence, skew incidence, reflection, transmission, reflexivity



$J_{in} = J_{tr} + J_{refl}$

reflection and transmission



$$\frac{\sin\alpha}{\sin\beta} = \frac{c_1}{c_2}$$

Snellius-Descartes

Reflexivity: $R = \frac{J_{refl}}{J_{in}} = \left(\frac{Z_1 - Z_2}{Z_1 + Z_2}\right)^2$

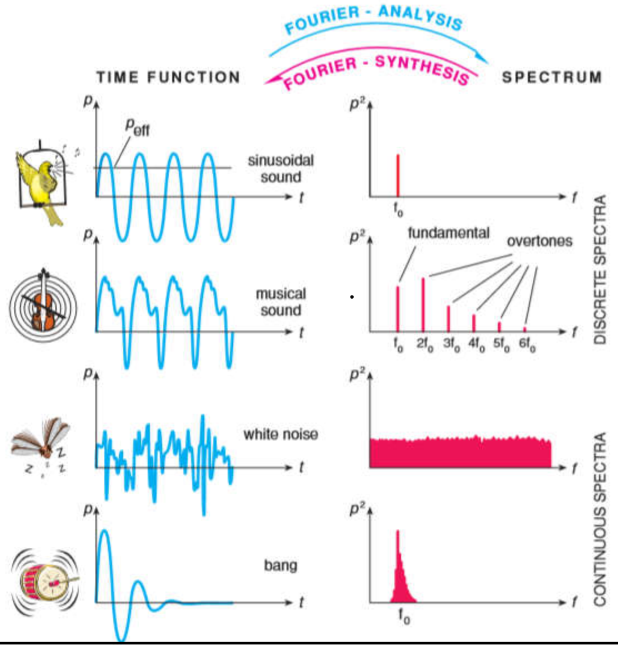
Physical properties of sound and sensory perceptions

J ⟶ loudness

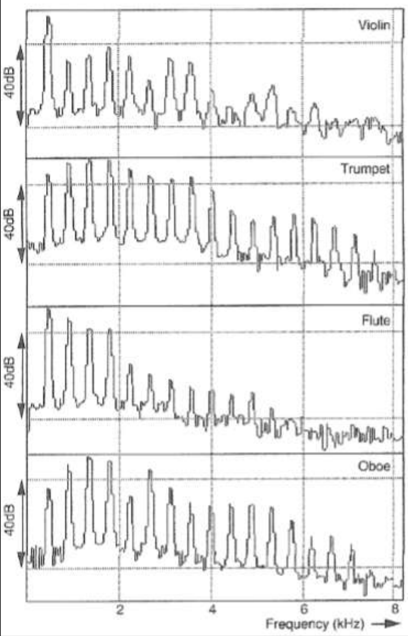
f ⟶ pitch

spectrum ⟶ tone color (timbre)

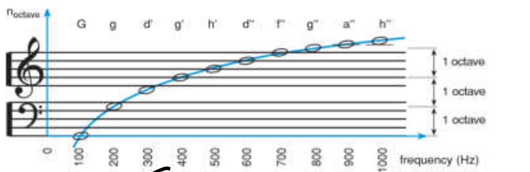
Spectrum of sound - pitch, timbre (tone colour)

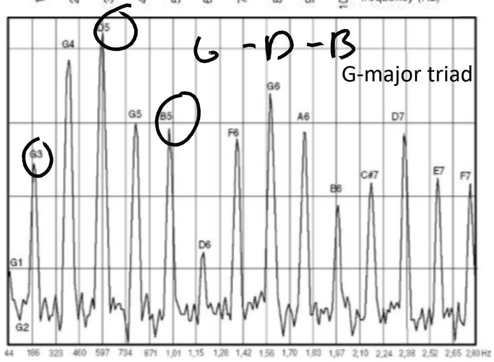


Harmonic orvertone spectra



a-sound (440 Hz) spectrum of four musical instruments

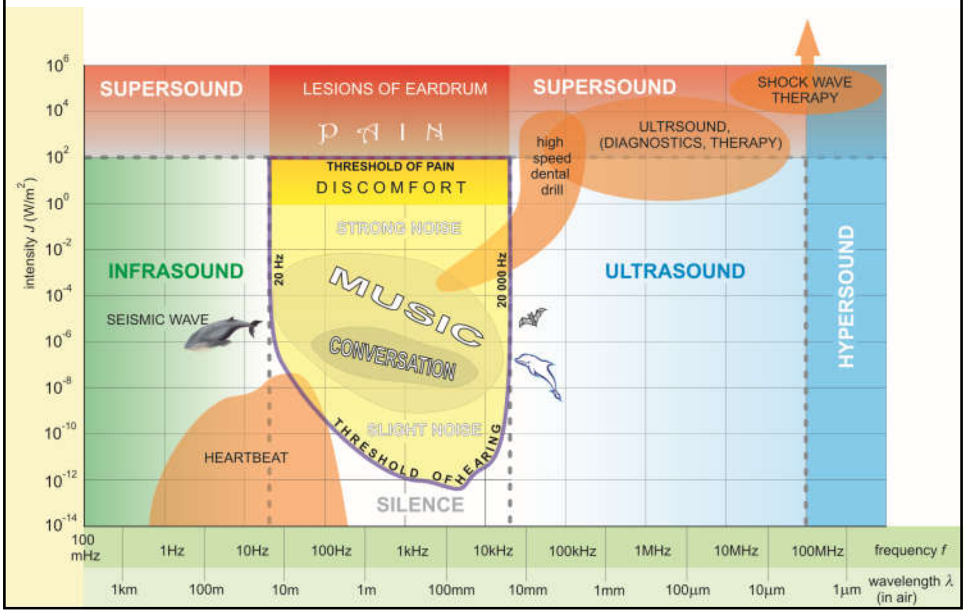




g-sound (196 Hz) spectrum of violin

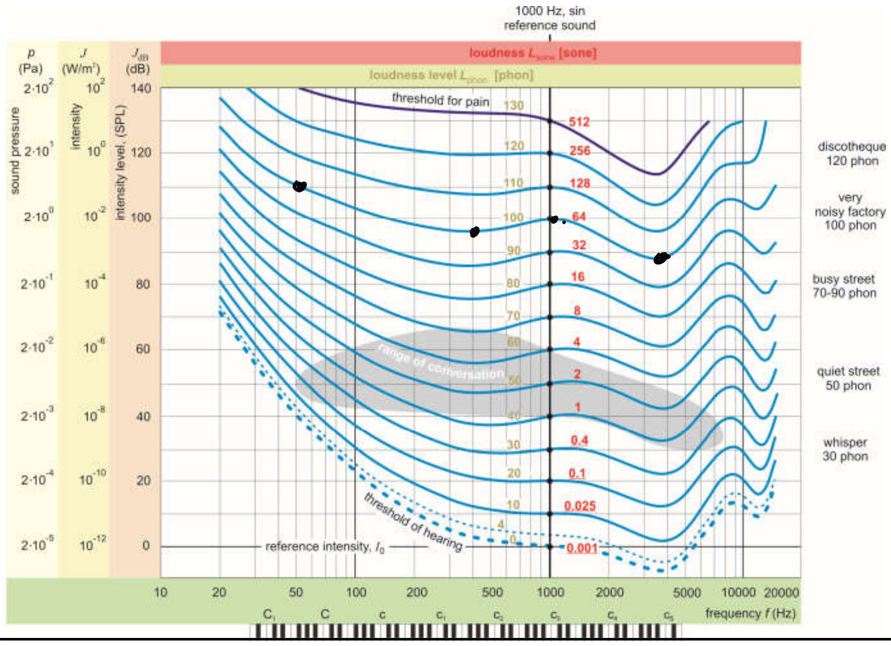
Classification of mechanical waves

frequency and intensity



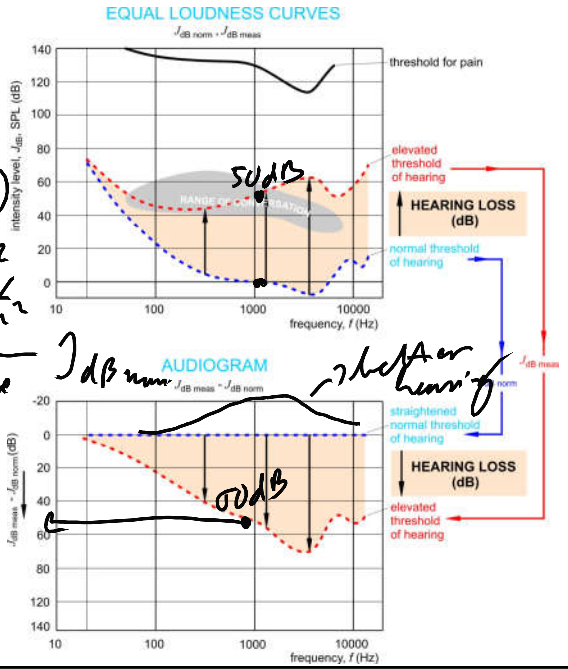
Equal-loudness curves

Physics of the senses - psychophysics



Audiometry

Intensity level



Medical applications of ultrasound

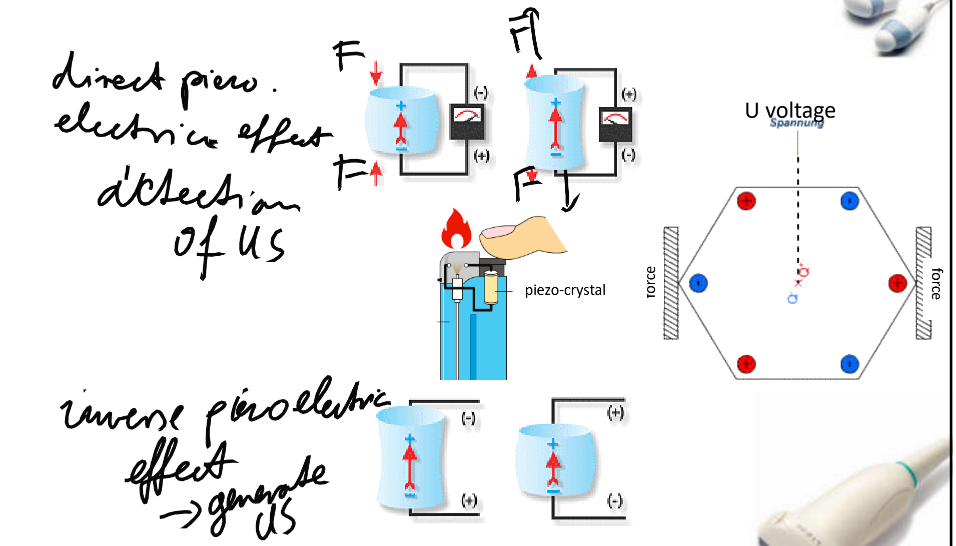
A. Diagnostics (Sonography) – US reflection

1. Generating US
2. Pulse-echo method
3. Image types
4. Measurement of blood flow

B. Therapy – US absorption

Generating US

Piezoelectric crystal, transducer



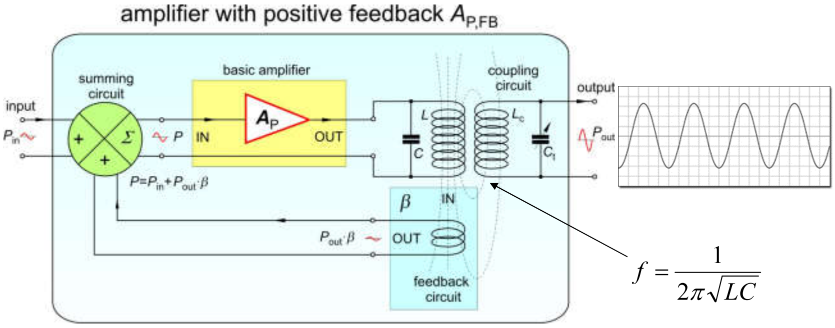
<u>Diagnostics:</u> f = 1 – 10 MHz, J ~ mW/cm²

<u>Therapy:</u> f = 0,8 – 1,2 MHz, J ~ W/cm²

Generating US

Source of the electrical signal – sine wave oscillator

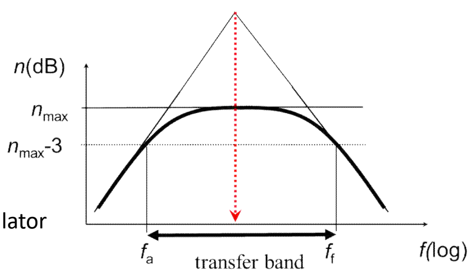
amplifier with positive feedback $A_{P,FB}$



$$f = \frac{1}{2\pi\sqrt{LC}}$$

$$A_{U,\,\text{feedback}} = \frac{A_U}{1-\beta A_U}$$

∞ 1



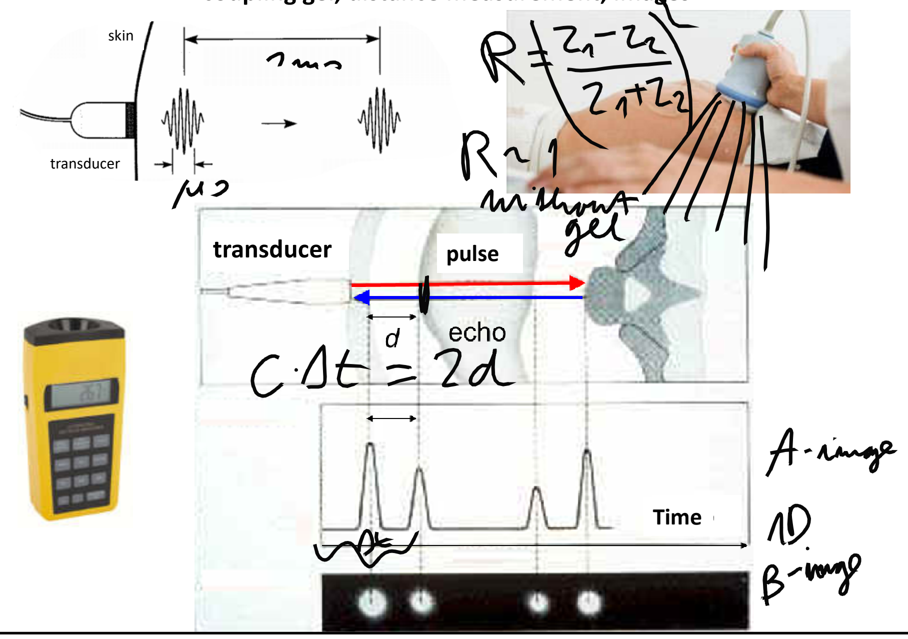
amplifier with positive feedback

βA_U=1, amplification = „infinity" sine wave oscillator

no input signal, output signal: sine voltage

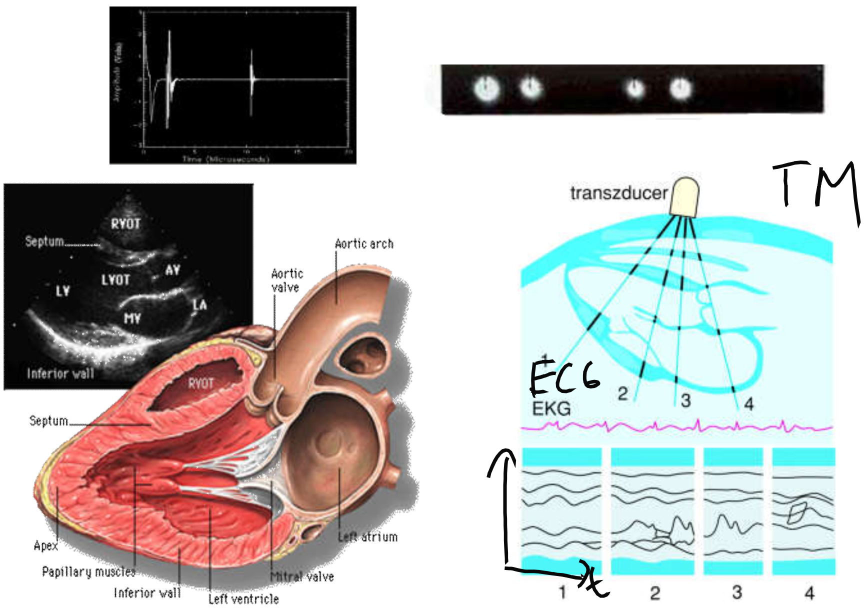
US imaging – pulse-echo method

coupling gel, distance measurement, images



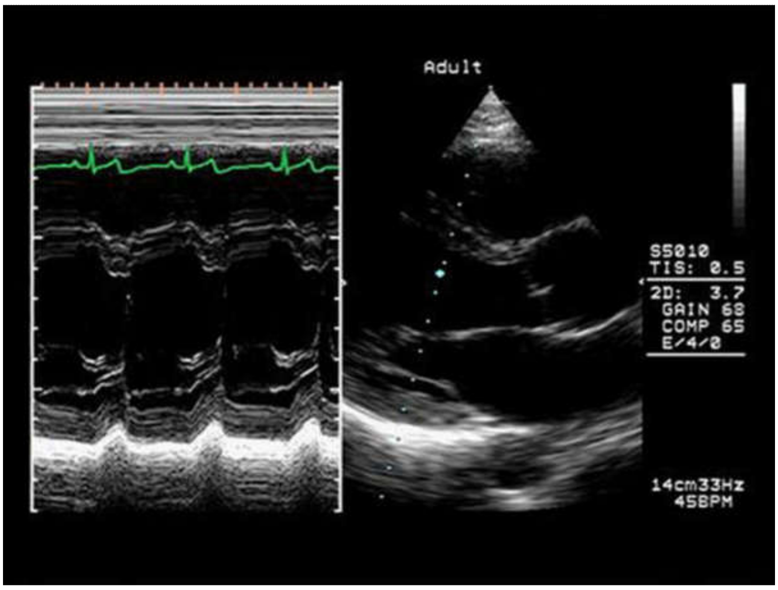
Types of US images

A-image, 1D B-image, 2D B-image, TM-image



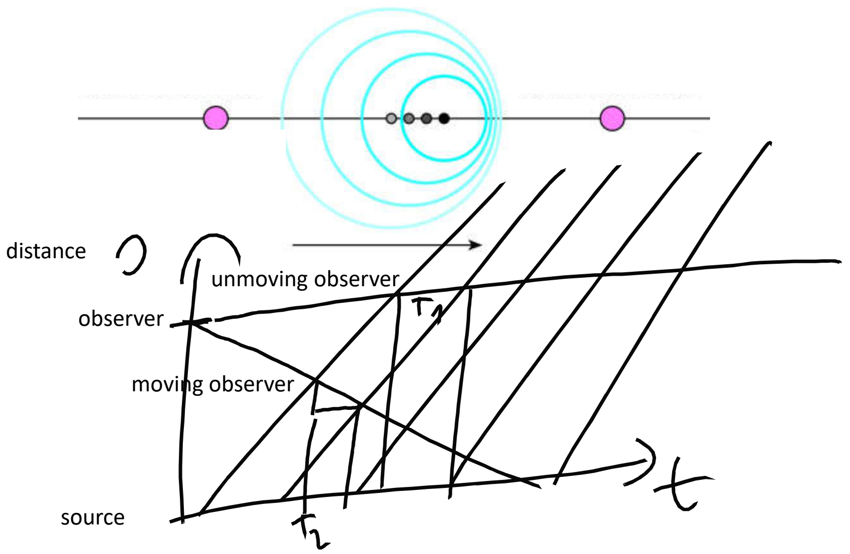
Types of US images

TM image **B image**



Doppler phenomenon

observer and source of radiation move relative to eachother



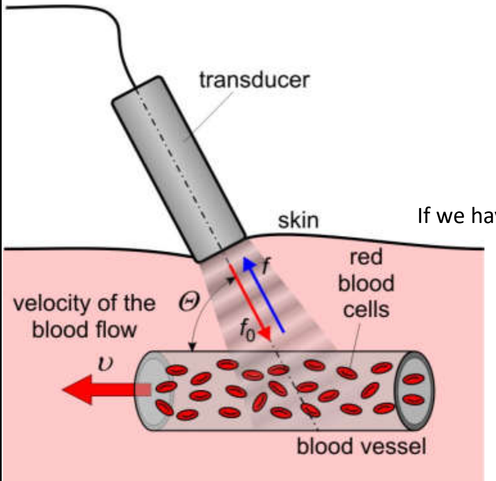
T1 > T2 ---- f1<f2, if the observer moves toward the source, higher f is heard

Continous wave(CW) Doppler measurement

separate emitter and reciever (near to each other), blood flow velocity

$$f_{New} = f_0 \pm f_0 \cdot \frac{v}{c}$$

(+ nearer, − away; $f_0 \cdot \frac{v}{c}$: Doppler shift)



If we have moving reflecting surface, 2*v is needed

$$f = f_0 \pm f_0 \cdot \frac{2v}{c}$$

(Doppler shift)

If we the reflecting surface does not move paralell with the US beam, 2* v cosΘ is needed

US therapy

mechanical and/or heat effect

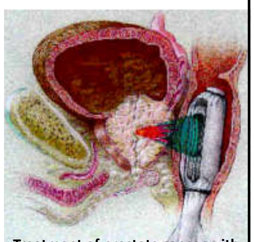
A. low intesity: micromassage – therapy of joints, muscle relaxation, pain relief and dilatation of blood vessels

B. High intesity: destructive effect
binding forces between the cells changed
free radical formation, H_2O_2, DNS chain breaks

1. *hypertermic therapy*
absorption – energy converted to heat

2. *cavitation* – HIFU - therapy (High Intensity Focused Ultrasound)

3. *dentistry:* removing plaques (20-40 kHz)



Treatment of prostate cancer with US source placed in the colon