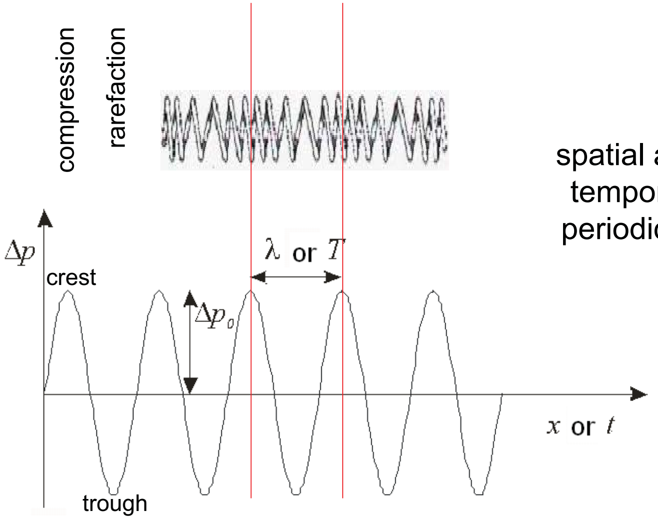
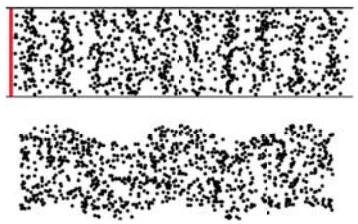
Sound: mechanical wave

spring

function



spatial and temporal periodicity



longitudinal wave
(in the interior of liquids and gases only this type)

transverse wave

hydrostatic pressure

pressure change, sound pressure

$p_{total} = p_{hydrostat} + \Delta p$

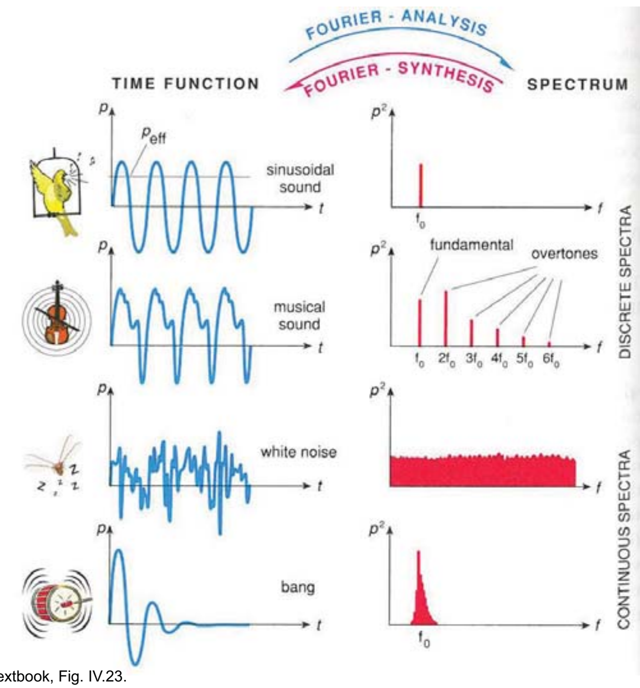
pressure DC + AC

amplitude phase

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

$c \cdot T = \lambda, \quad c = f \cdot \lambda$

Textbook, Fig. II.46.

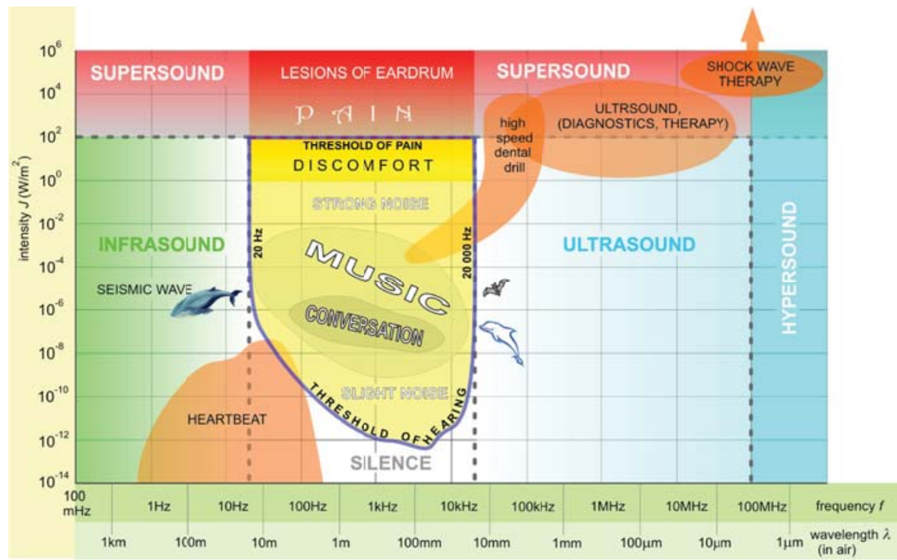


pitch:
frequency of the fundamental

tone colour:
relative strengths of overtones/harmonics (spectrum)

Textbook, Fig. IV.23.

Frequency and intensity regions of sounds



Lab. manual, Audiometry.

The role of elastic medium

$$\kappa = \frac{-\frac{\Delta V}{V}}{\Delta p}$$

compressibility
relative volume decrease over pressure

$$c = \frac{1}{\sqrt{\rho\kappa}}$$

speed of sound

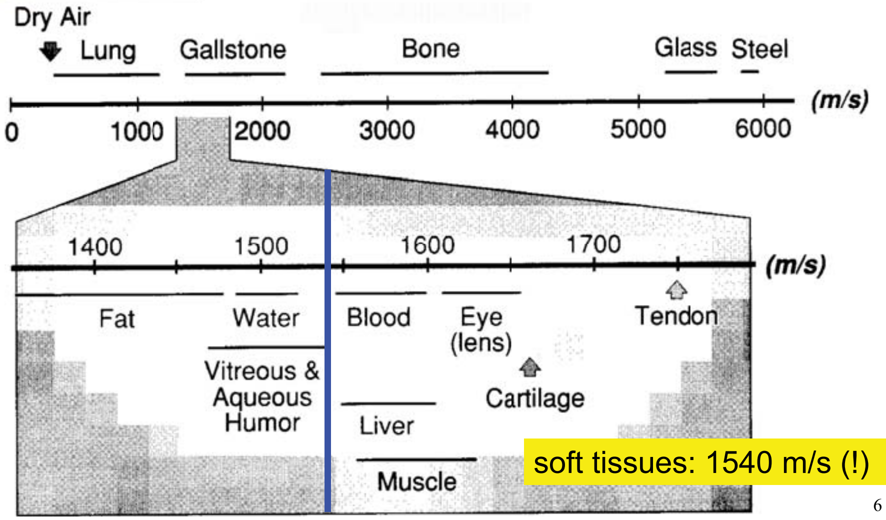
$$Z = \frac{p}{v} = \frac{p_{max}}{v_{max}}$$

acoustic **impedance** (definition)

$$\boxed{Z = c\rho} = \sqrt{\frac{\rho}{\kappa}}$$

acoustic **impedance** (useful form)

Speed of sound/US in different media



Intensity of US

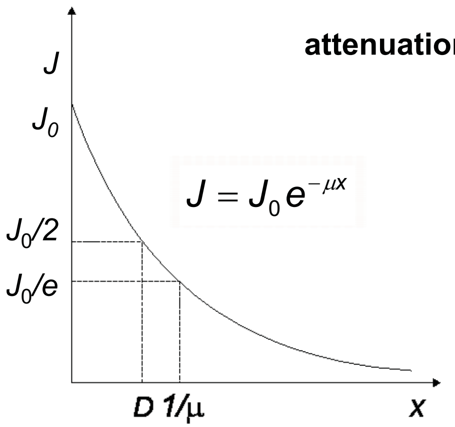
$$J = \frac{1}{Z}\Delta p_{eff}^{\ 2}$$

intensity = energy-current density

$$P_{el} = \frac{1}{Z_{el}}U_{eff}^{\ 2}$$

electric analogy

Loss of energy during propagation (absorption)



attenuation: $\alpha = 10 \cdot \lg\frac{J_0}{J}$ dB

$\alpha = 10 \cdot \mu \cdot x \cdot \lg e$ dB

μ is proportional to frequency in the diagnostic range

specific attenuation: $\boxed{\frac{\alpha}{f \cdot x}}$

μ is proportional to frequency in the diagnostic range

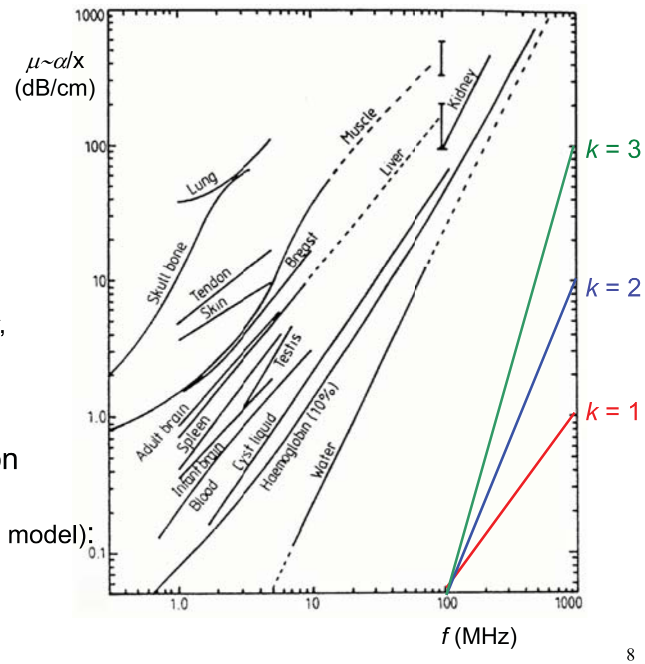
$\mu \sim f^k, \quad k \sim 1(?)$

$\log\mu \sim k\log f$

if the graph is a linear, the power function approximation is valid

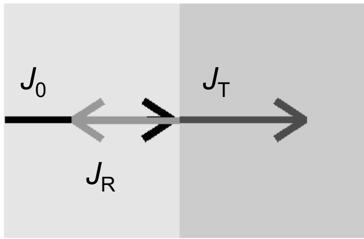
specific attenuation for soft tissues (homogeneous tissue model):

$$\boxed{\frac{\alpha}{f\,x} \sim 1\frac{\text{dB}}{\text{cm MHz}}}$$



Phenomena at the boundary of different media

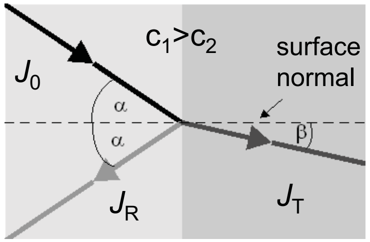
normal/perpendicular incidence



$J_0 = J_R + J_T$

reflection and transmission (penetration)

skew incidence



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

Snellius-Descartes

Textbook, Fig. II.47.

Reflection (normal incidence)

reflectivity:

$$R = \frac{J_{\text{reflected}}}{J_{\text{incident}}} = \left(\frac{Z_1 - Z_2}{Z_1 + Z_2}\right)^2$$

"full" reflection:

$Z_1 << Z_2, \quad R \approx 1$

boundary surface	*R*
muscle/blood	0.001
fat/liver	0.006
fat/muscle	0.01
bone/muscle	0.41
bone/fat	0.48
soft tissue/air	0.99

Generation of US. Piezoelectric effect

production: inverse ~
detection: direct ~

source of electric signal (sine wave oscillator)+ transducer (piezo-crystal)

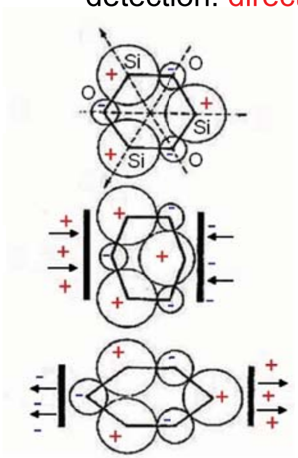
(a) Center of charge of positive and negative charges coincides.

(b) and (c) As a result of pressure , the charge centers are separated, i.e. a potential difference arises (direct ~).
The crystal is deformed when voltage is applied (inverse ~).

a

b

c



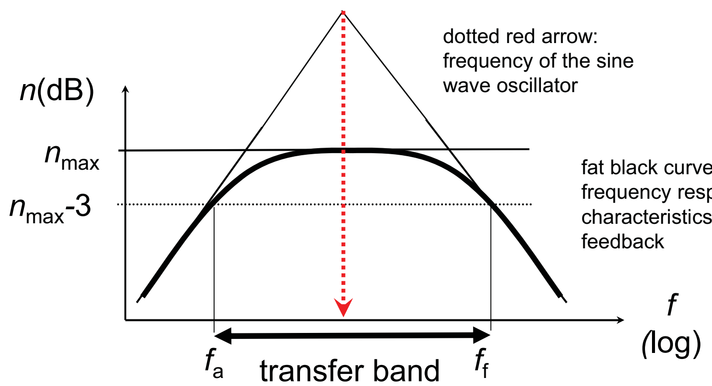
at home:
gas igniter

Source of electric signal : sine wave oscillator

amplifier with positive feedback

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

βA_U=1, amplification = „infinity" ➡ sine wave oscillator
no input signal, output signal: sine voltage

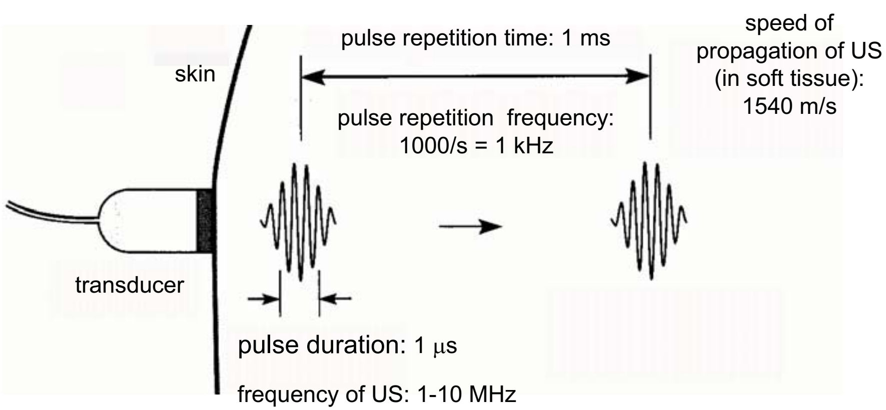


dotted red arrow: frequency of the sine wave oscillator

fat black curve: frequency response characteristics without feedback

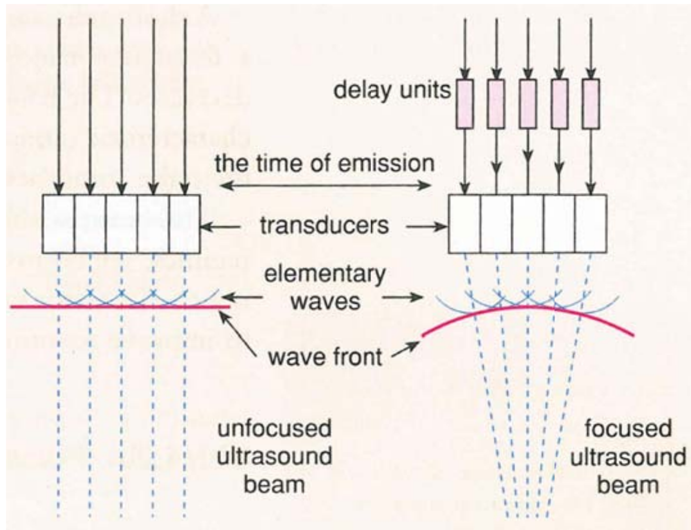
Characteristic of US pulses

transducer: transmitter and receiver is the same unit
time sharing mode: pulses instead of continuous wave US



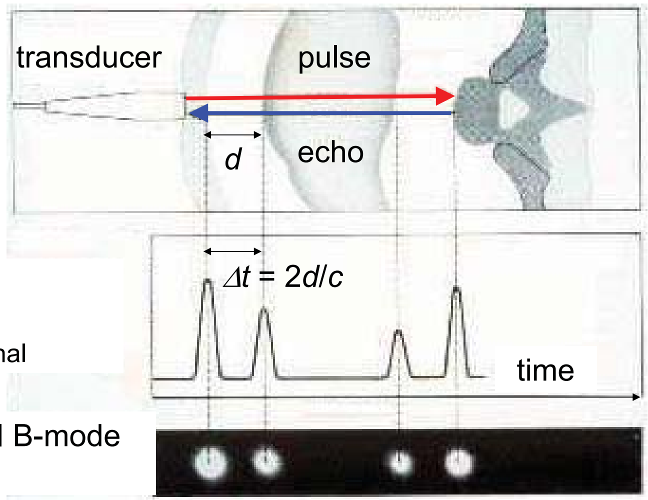
Textbook, Fig. VIII.32.

Electronic focusing



cf. Textbook Fig. on p.507

Receiving the echos

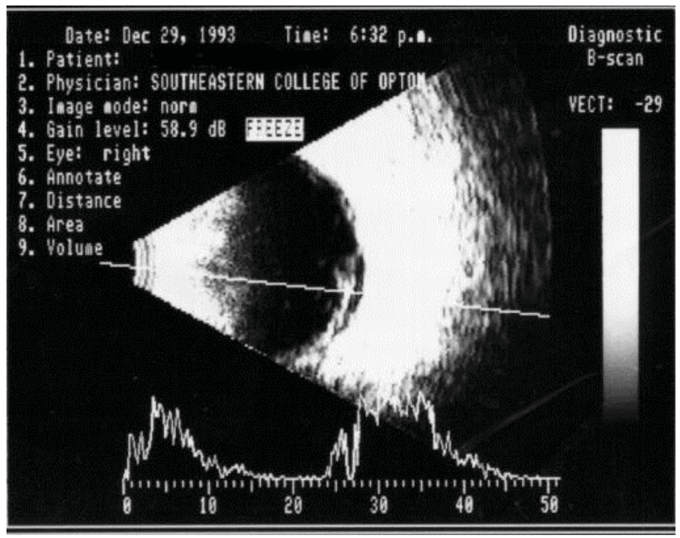


A-mode
(***A***mplitude)
only 1-dimensional

1-dimensional B-mode
(***B***rightness)

cf. Textbook Fig. VIII.33

2-dimensional B-mode and A-mode
(used in opthamology)



real speed of propagation for the accurate determination of distances:

cornea: 1641 m/s

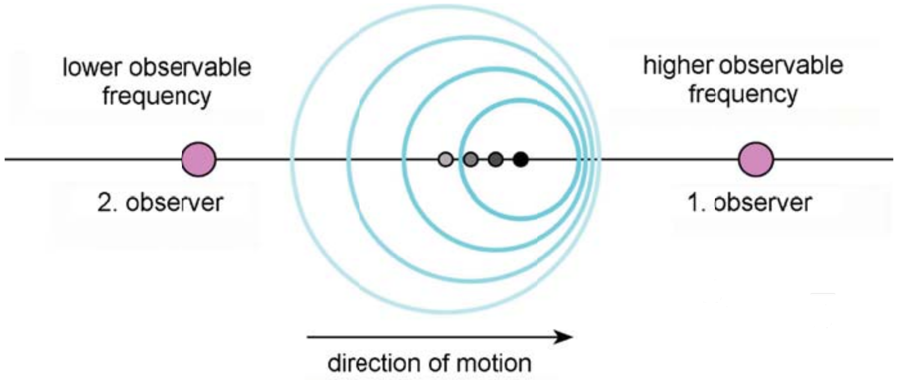
aqueos humour: 1532 m/s

crystalline lens: 1641 m/s

vitreous body: 1532 m/s

Doppler phenomenon

„The pitch of a train whistle seems to get higher as it approaches, then seems to lower as the train whistle moves away.” (C. Doppler, 1842)



Teextbook Fig. VIII.39

f': **observed frequency**, f : original frequency

(a) standing source and moving observer (v_O)
+: observer approches the source
–: observer moves away from the source

$$f' = f\left(1 \pm \frac{v_O}{c}\right)$$

(b) moving source and standing observer
(if $v_S \ll c$, then „same” as (a))

$$f' = \frac{f}{1 \mp \frac{v_S}{c}}$$

(c) moving source and moving observer

$$f' = f\,\frac{1 \pm \frac{v_O}{c}}{1 \mp \frac{v_S}{c}}$$

(d) moving reflecting object (surface),
(if $v_R \ll c$)

$$f' = f\left(1 \pm \frac{2v_R}{c}\right)$$

Doppler frequency = frequency change = frequency shift

if v_i, $v_R \ll c$ (i= S or O)

rearranging equation (a)
moving source or observer:

$$\Delta f = f_D = \pm \frac{v_i}{c} f$$

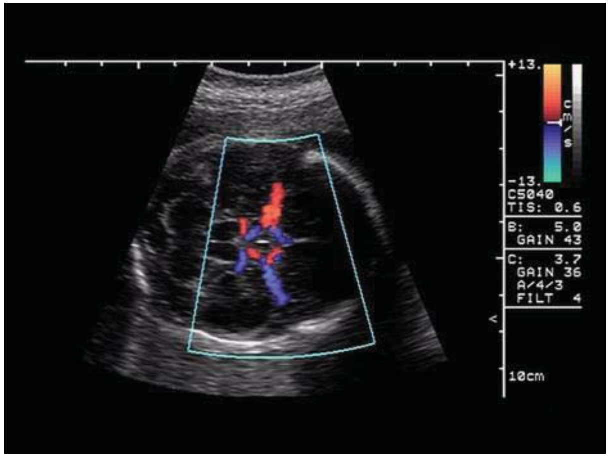
rearranging equation (d)
moving reflecting object or surface:

$$\Delta f = f_D = \pm 2 \frac{v_R}{c} f$$

if v and c are not parallel, then $v \cos\Theta$ should be used instead of v (remark: if $\Theta = 90°$, $f_D = 0$)

Colour coding

towards the transducer: warm colours
away from the transducer: cold colours



BART: Blue Away Red Towards

Safety

in the diagnostics:

10 mW/cm^2 = 100 W/m^2

cf. pain threshold: 10 W/m^2

in the therapy: 1 W/cm^2