Ultrasound

for pharmacy students

Dr. Tamás Bozó
assistant professor
Department of Biophysics and Radiation Biology
08.03.2022.

SEMMELWEIS
EGYETEM 1769

Lecture topics

Topics

- **Sound** *(repetition - see lecture 4)*
  - General properties
  - Propagation
  - Interaction with matter
- **Ultrasound** (US)
  - Piezoelectric effect, inverse piezoelectric effect
  - US generation and detection
  - Pulse-echo principle
  - Imaging modes
  - Doppler methods

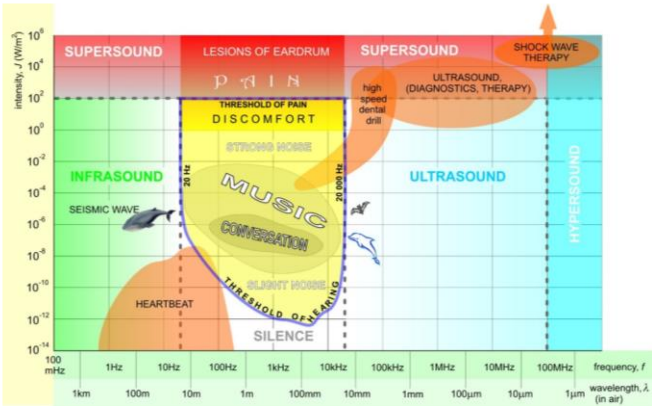
Related practice topics

- Ultrasound
- Audiometry
- (Sine Wave Oscillator)

Textbook chapters

- II./2.4 Sound, ultrasound
- VIII./4.2. Ultrasound Imaging – Direct Tomography 2.

Sound properties

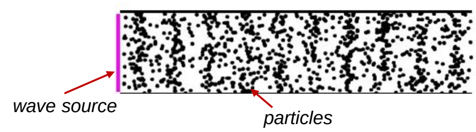


Sound

- Mechanical/pressure wave (propagates in a medium)

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

- Intensity: $J = \frac{1}{2Z}\Delta p_{max}^2 = \frac{1}{Z}\Delta p_{eff}^2 \quad \left[\frac{W}{m^2}\right]$
- Longitudinal in gases and fluids (soft tissues)



Propagation of sound

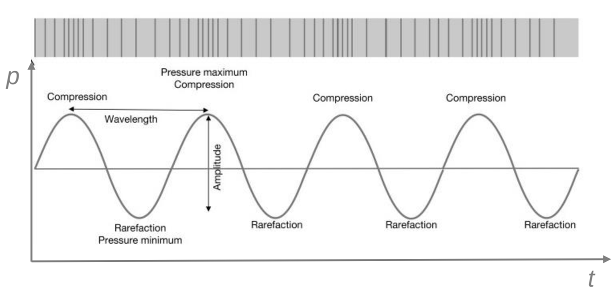
Sound

- Speed [m/s]:

$$c = f \cdot \lambda$$

f : frequency
λ : wavelength

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



Properties of medium

- Compressibility [1/GPa]:

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

$-\frac{\Delta V}{V}$: rel. volume decrease
Δp : unit pressure increase

- Acoustic impedance [kg/(m²·s)]:

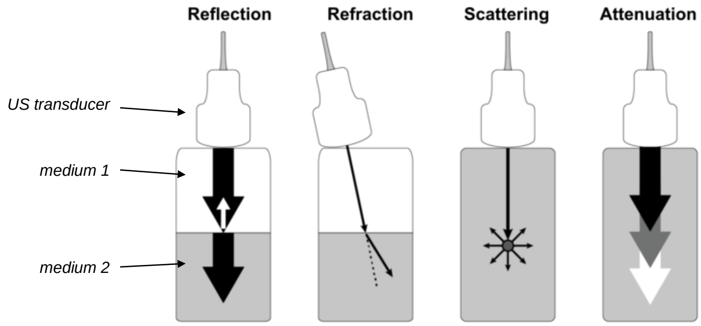
$$Z = \frac{p}{v} = \frac{p_{max}}{v_{max}}$$

p : pressure
v : particle velocity

$$Z = c \cdot \rho$$

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

Interaction with the matter – I.



https://icurevisited.com/lus/

Interaction with the matter – II.

Absorption – in homogeneous medium

- Attenuation law:

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

$$\mu = \mu_{absorption} \cdot \mu_{scattering}$$

$$\mu \sim f \ \ (in\ diagnostic\ US\ range)$$

- Damping [dB]:

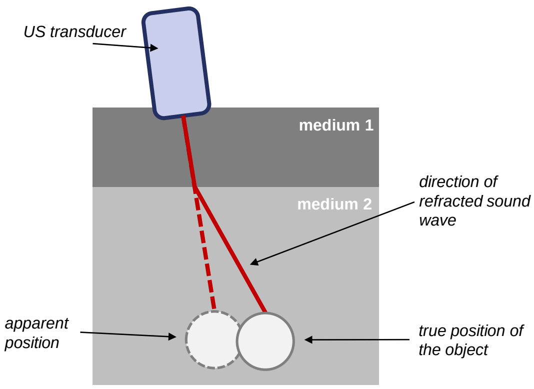
$$\alpha = 10 \cdot lg\frac{J_0}{J} = 10 \cdot \mu \cdot x \cdot \lg e$$

- Specific damping [dB/cm·MHz]:

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

material	ρ [kg/m³]	κ [1/GPa]	c [m/s]	Z [kg/(m²·s]	α/(f·x) [dB/(cm·MHz]
air	1.3	7650	331	$4.3 \cdot 10^2$	1.2
water (36°c]	994	0.42	1530	$1.53 \cdot 10^6$	-
soft tissue	1060	0.40	1540	$1.63 \cdot 10^6$	0.3-1.7
liver	1060	0.38	1560	$1.65 \cdot 10^6$	0.94
muscle	1060	0.40	1568	$1.63 \cdot 10^6$	1.3-3.3
blood	1060	0.38	1570	$1.61\text{-}1.66 \cdot 10^6$	0.18
dense bone	1700	0.05	3600	$6.12 \cdot 10^6$	20.0

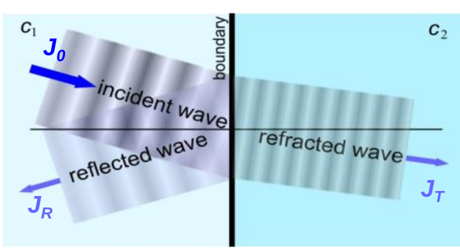
Interaction with the matter – III.

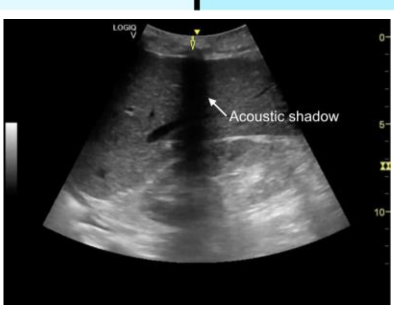


Refraction – at a boundary surface

- Apparent positions of object may be false → distortion of reconstructed geometry
- Refraction is governed by Snell's law

Interaction with the matter – IV.





Reflection at a boundary surface

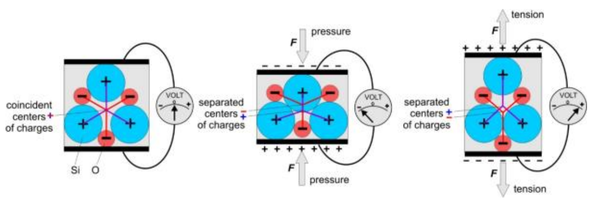
- Reflexivity:

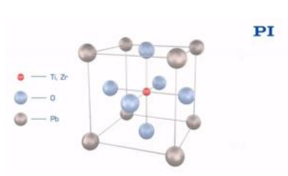
$$R = \frac{J_R}{J_0} \qquad R = \left(\frac{Z_1 - Z_2}{Z_1 + Z_2}\right)^2$$

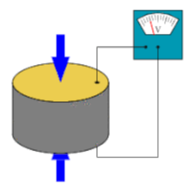
Boundary surface	R
muscle / blood	0.0009
fat / liver	0.006
fat / muscle	0.01
bone / muscle	0.41
bone / fat	0.48
soft tissue / air	0.99

- Time Gain Compensation (TCG); Depth Gain Control (DCG): echo signals from deeper tissues are amplified more

Generation and detection of ultrasound



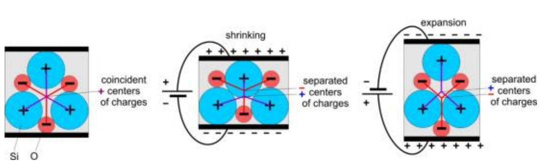


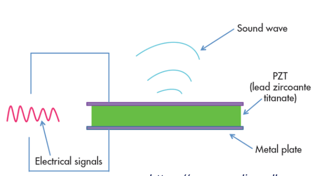


Piezoelectric effect:

- Certain materials show piezoelectricity,
- e.g.: quartz, Lead Zirconate Titanate (PZT); $BaTiO_3$,
- Upon deformation they become electrically polarized,
- Potential difference appears between electrodes places on opposite sides,
- Mechanical oscillations (e.g. ultrasound) can be detected as a voltage signal by this phenomenon.
- *Piesmos* [an.greek] = pressure, compression

Generation and detection of ultrasound – II.



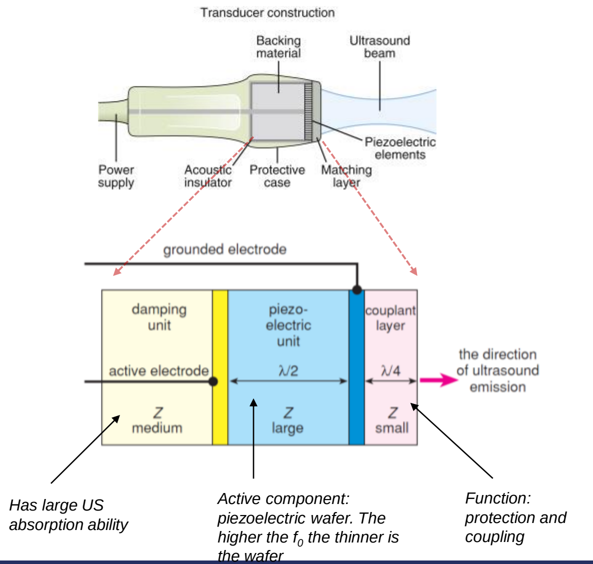


https://www.audiowell.com

Inverse piezoelectric effect:

- If voltage is applied on electrodes places on opposite sides of the same material,
- Deformation occurs, the crystal thickness changes.
- Alternating voltage leads to periodically changing thickness, and thus an oscillating mechanical wave (i.e. sound).
- Sound frequency coincides with the AC frequency.
- Ultrasound can be generated by this phenomenon.

Generation and detection of ultrasound – III.



Transducer

- Signal converting device (electromechanical transducer)
- Consist of piezoelectric materials (wafers)
- Able to convert electric signal to US and US to electric signal → produces and detects US
- Excitation using resonance frequency → maximal efficiency of US production and detection
- Eigenfrequency vibration mode is assisted by design geometry (thickness of layers)
- High frequency AC voltage is produced by a sine wave oscillator (positive feedback)

Diagnostic application of ultrasound

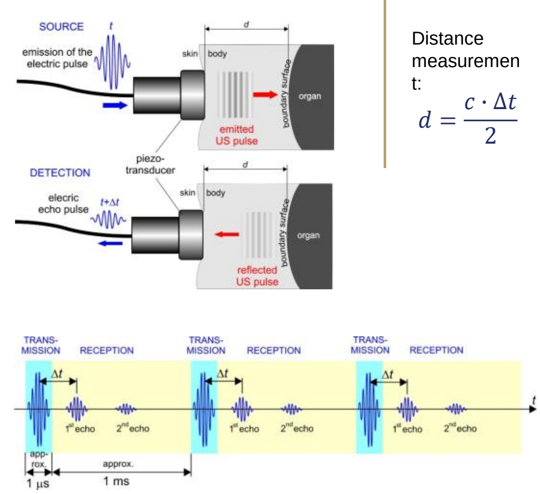
Diagnostic ultrasound

parameters	~min.	~max.
f	**2 MHz**	**15 MHz**
λ (in muscle)	0.78 mm	0.1 mm
penetration depth	12 cm	1.6 cm
lateral limit of resolution	3.0 mm	0.4 mm
axial limit of resolution	0.8 mm	0.15 mm

Diagnostic use

- Based on reflection from surfaces of biological tissues having different acoustic impedances
- Measured parameters: voltage pulses (generated by US pulse and echoes); time.

Pulse-echo mode



Distance measurement:

$$d = \frac{c \cdot \Delta t}{2}$$

Imaging modes

A image

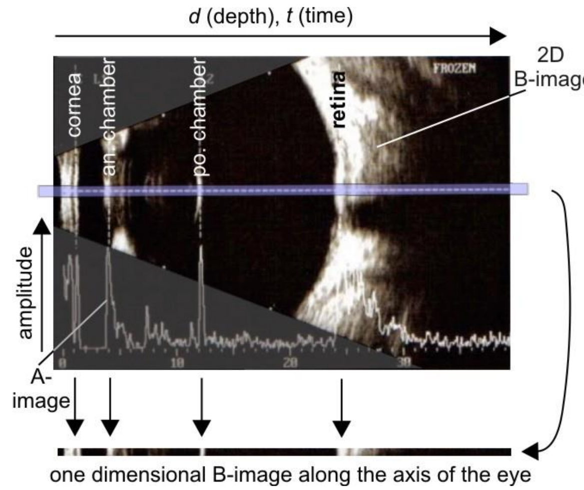
- One dimensional : single transducer, one US beam
- Amplitude modulation: signal amplitude (echo signal) plotted as a function of time (or distance)

1D B image

- One dimensional : single transducer, one US beam
- Brightness modulation: signal amplitude (echo signal) is color coded as brightness (greyscale) on a horizontal time (or distance) scale

2D B image

- Two dimensional : fan shape plane is scanned by a transducer array → series of 1D B images
- Brightness modulated

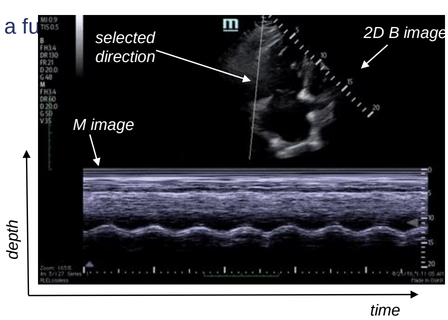


Goat eye

Imaging modes – II.

M image - motion

- 1 direction is chosen form a 2D B image
- Sequence of 1D B images if plotted on horizontal time scale
- Provides information of position of a surface/object as a fu



tricuspid annular motion (TAPSE)

3D image (reconstruction)

- Computer aided reconstruction of a 3D image from several 2D B images (tomography)

4D image (reconstruction)

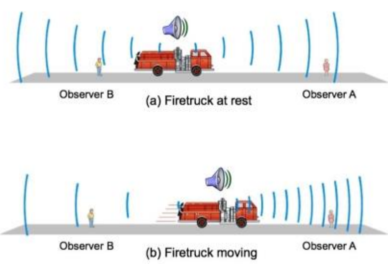
- Movie from a sequence of several 3D images.
- 4^{th} dimension: time

Doppler methods

Horn of speeding car

Doppler effect

- If the wave source and an observer are in motion relative to each other, the observer records a frequency different from the actually emitted.



moving away – f' decreases
lower pitch observed

approaching – f' increases
higher pitch observed

US reflected from a moving boundary surface

- Reflecting surface acts as it were a sound source
- Observed frequency [Hz]:

$$f = f_0\left(1 \pm 2\frac{v}{c}\right)$$

***f_0* :** emitted frequency

v: velocity component of the reflecting surface in the direction of us propagation

c: US velocity

±: approaching or moving away

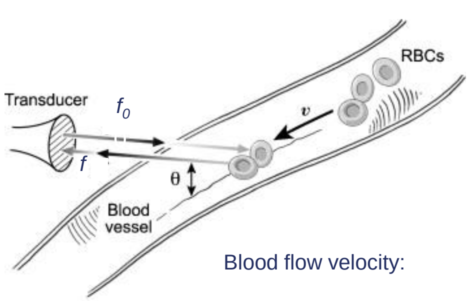
- Doppler shift („Doppler frequency”):

$$f_D = f - f_0 = f_0\frac{2v\cos\theta}{c}$$

SEMMELWEIS EGYETEM 1769 | Department of Biophysics and Radiation Biology | 15

Doppler methods – II.

Doppler flow meter

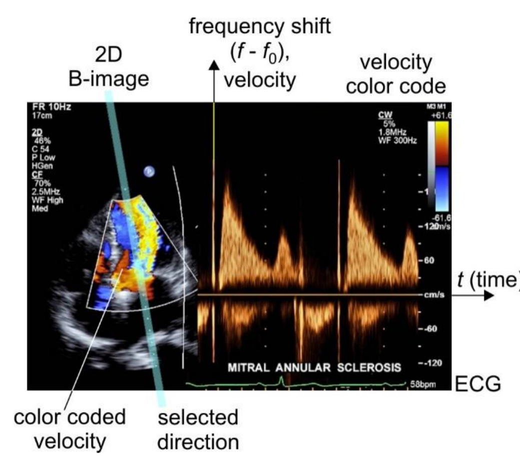


Nandan S. J Cardiol. 2009;54:347

Blood flow velocity:

$$v = \frac{c(f - f_0)}{2f_0\cos\theta}$$

Doppler imaging



SEMMELWEIS EGYETEM 1769 | Department of Biophysics and Radiation Biology | 16

Thanks for your attention

Dr. Tamás Bozó

SEMMELWEIS
EGYETEM 1769