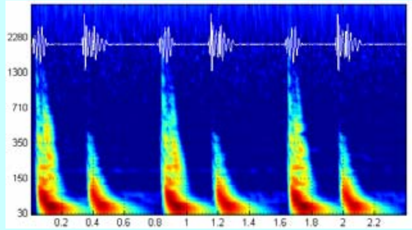
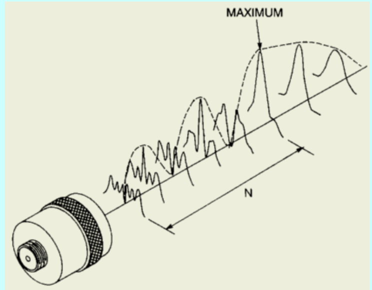
Medical application of US

Therapy – due to absorption of US

Diagnostics – due to reflection of US

Physics of ultrasonography





Reflection of US

material	ρ [kg/m³]	κ [1/GPa]	c [m/s]	Z [kg/(m²·s)]
Air	1,3	7650	331	$0,00043 \cdot 10^6$
Lung	400	5,92	650	$0,26 \cdot 10^6$
Fat	925	0,51	1470	$1,42 \cdot 10^6$
Soft tissue	1060	0,40	1540	$1,63 \cdot 10^6$
Eye lens	1140	0,34	1620	$1,84 \cdot 10^6$
Done merrow	970	0,36	1700	$1,65 \cdot 10^6$
Bones (porous)	1380	0,08	3000	$2,2 – 2,9 \cdot 10^6$
Bones (solid)	1700	0,05	3600	$6,12 \cdot 10^6$

interface	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

If $R \approx 1$ → Total reflection

Reflection of US

material	c (m/s)	ρ (kg/m³)	Z (kg/m²s
pulp	1570	1000	$1,6 \cdot 10^6$
dentin	3800	2000	$7,6 \cdot 10^6$
enamel	6250	3000	$18,8 \cdot 10^6$
Al	6300	2700	$17 \cdot 10^6$
borosilicate	5300	3570	$18,9 \cdot 10^6$
amalgam	4350	7750	$33,7 \cdot 10^6$

interface	R
enamel/dentin	0,18
dentin/pulp	0,43
amalgam/dentin	0,40

Reflection of US

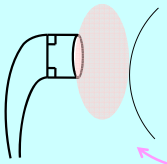
interface	R
muscle/blood	0,0009
fat/liver	0,006
fat/muscle	0,01
bone/muscle	0,41
bone/fat	0,48
soft tissue/air	0,99

Optimal coupling:

$$Z_{coup} = \sqrt{Z_1 \cdot Z_2}$$

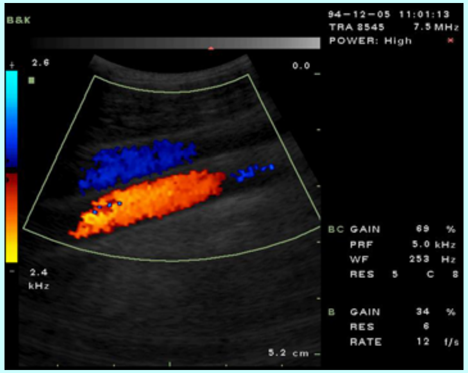
$Z_{gele} \sim 6{,}5 \cdot 10^6$ kg/(m^{2}s)

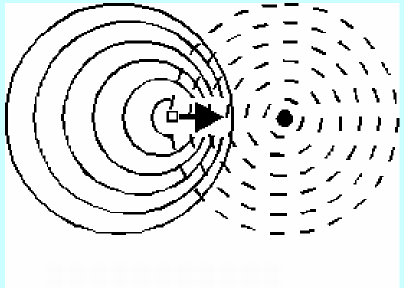
If $R \approx 1$ → Total reflection



Coupling material

US imaging. Modes of sonography. Doppler-echo.

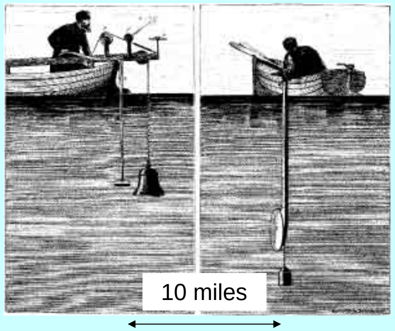


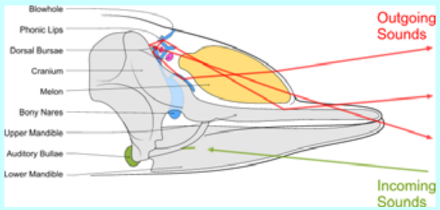


Echo principle

1794 - Spallanzani:
bat's navigation

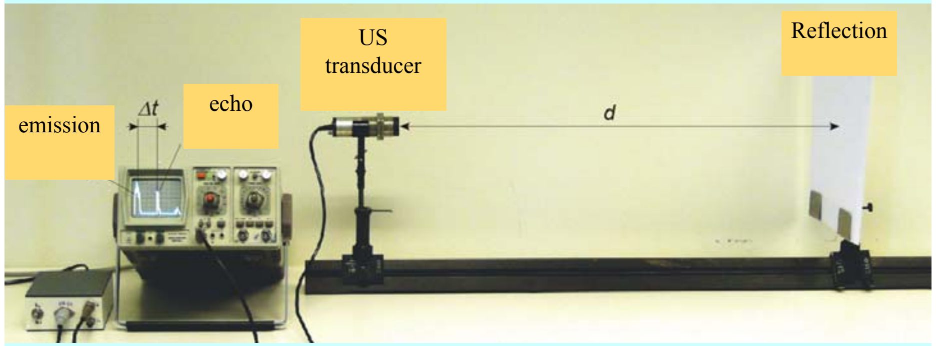
1822 - Colladen measured
the speed of sound in water



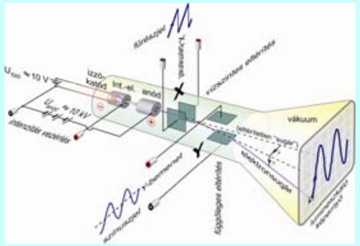


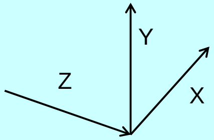
bottlenose dolphin

Echo principle

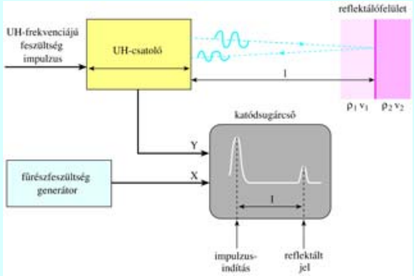


$c\Delta t = d + d = 2d$

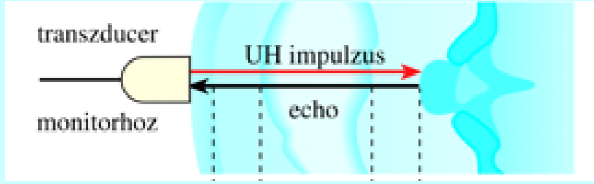




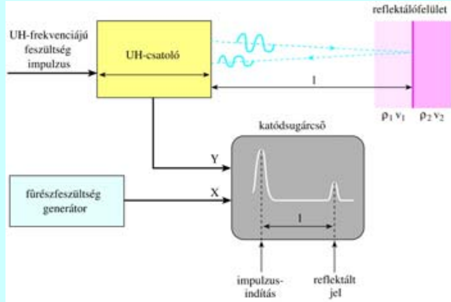
Deflection / controling	A-image
X	Time (→ axial distance)
Y	Amplitude (→ I_{refl})
Z	(Brightness)



A-image - *A*mplitude



One-dimensional only

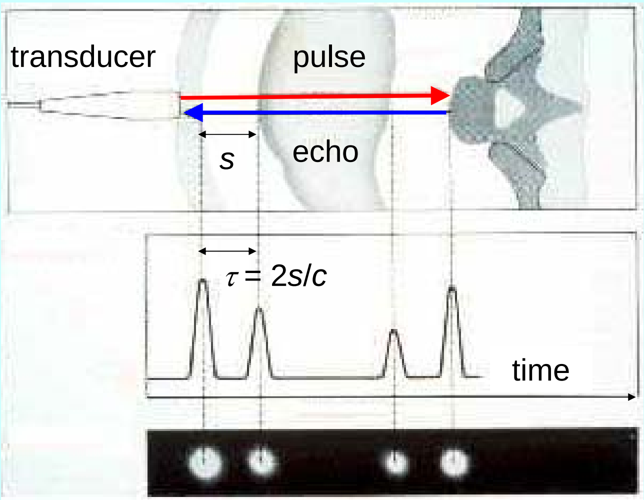


$c\Delta t = d+d = 2d$

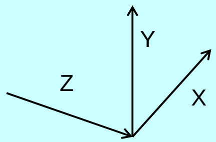
B-image - *Brightness*

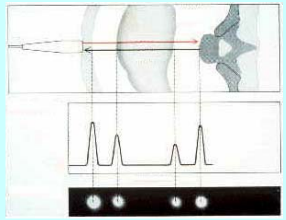
A-mode (***A***mplitude) only 1-dimensional

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



cf. Textbook Fig. VIII.33

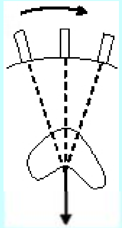


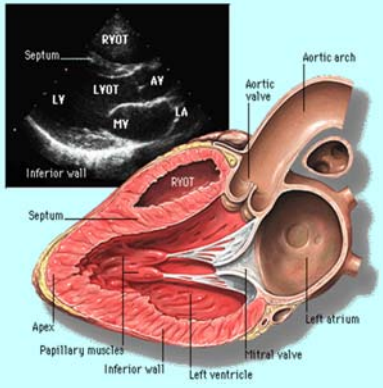


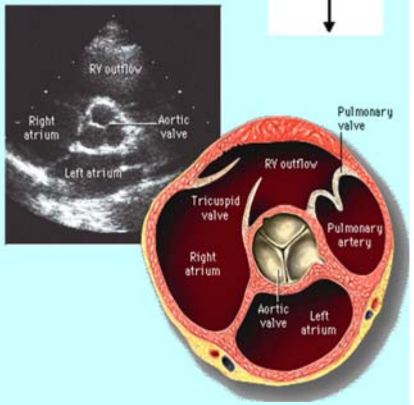
Deflection / controling	A-mode	1-dimensional B-mode
X	Time (→ axial distance)	Time (→ axial distance)
Y	Amplitude (→ I_{refl})	-
Z	(Brightness)	Brightness (→ I_{refl})

2-dimensional B-mode

moving
transducer

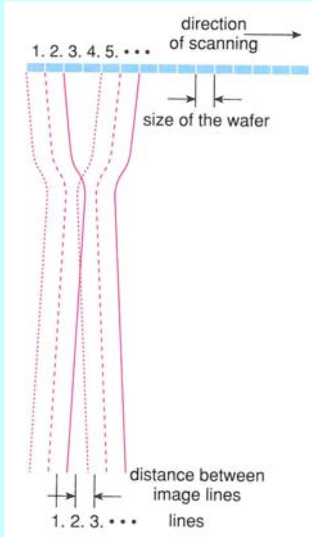




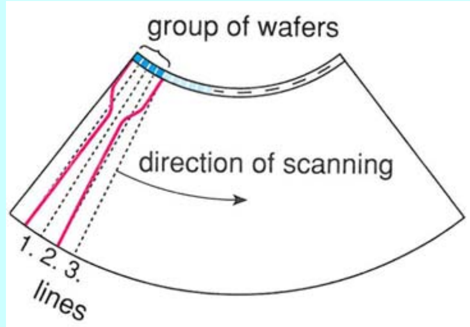


Scanning

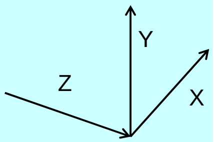
multi unit linear array

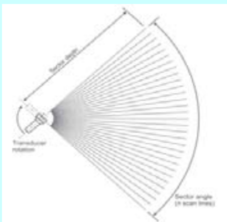


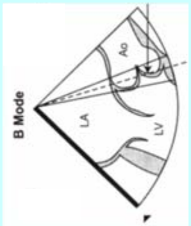
multi unit curved array

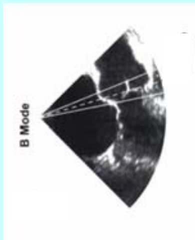


cf. Textbook Fig. VII. 36-37







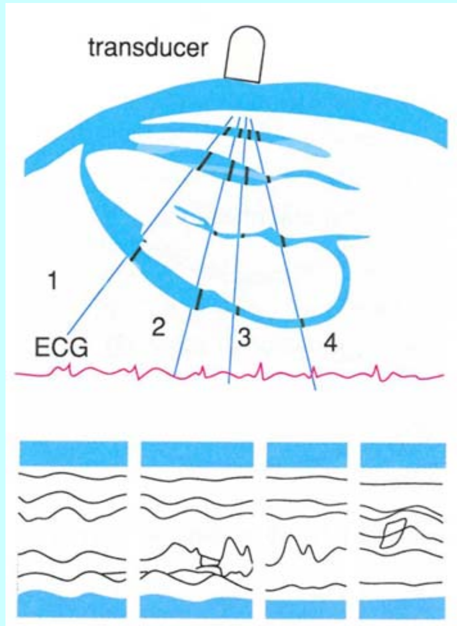


Deflection / controling	2-dimensional B-mode
X	Time (→ axial distance)
Y	Lateral distance
Z	Brightness (→ I_{refl})

TM-mode

ECG signal
for reference

(vertical)
time-dependent
1-dimensional
B-mode



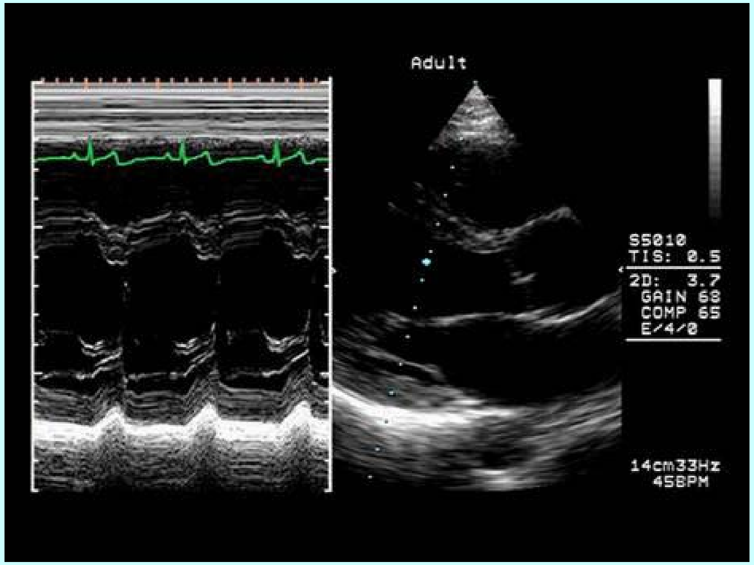
time →

(T)M-mode

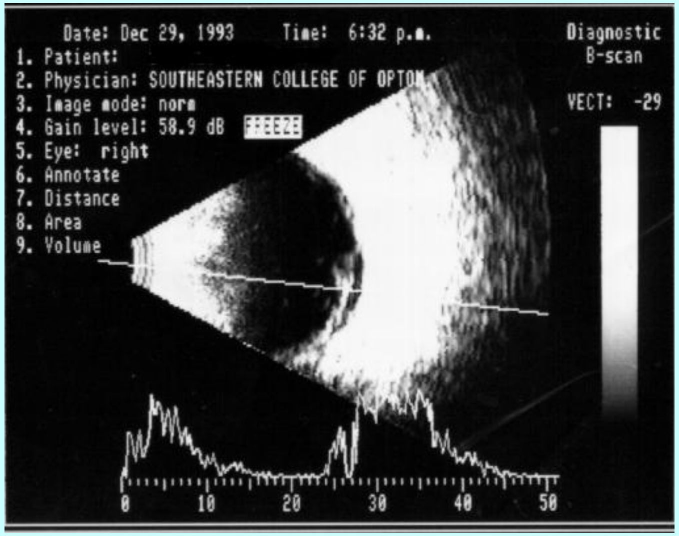
***T**ime–*
***M**otion*

Textbook Fig. VIII.34

TM-mode B-mode



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

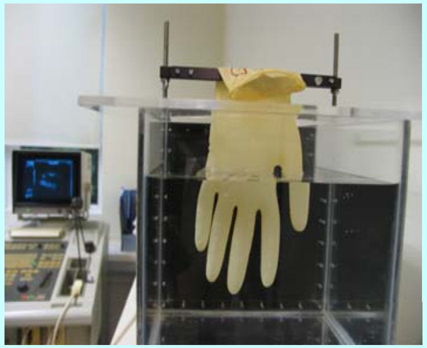
crystalline lens: 1641 m/s

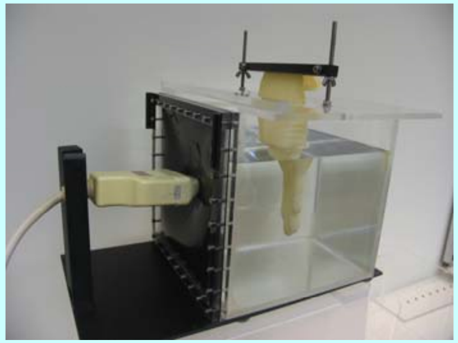
vitreous body: 1532 m/s

The object and the image

The object

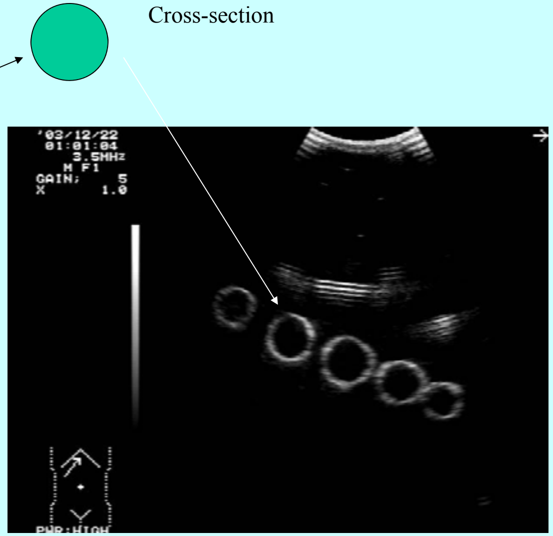
The object and the image





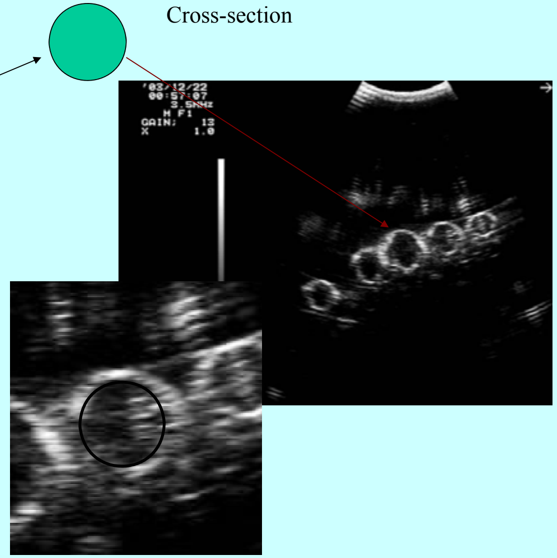
Imaging

The object and the image



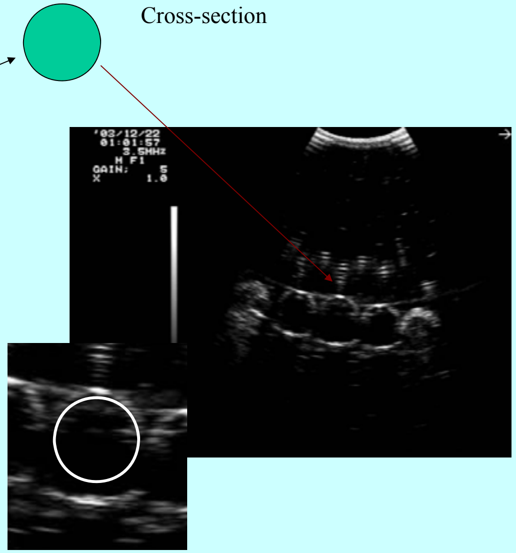
The image

The object and the image



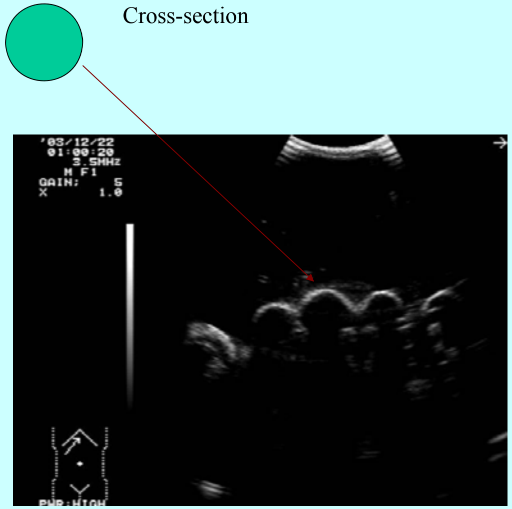
The image

The object and the image



The image

The object and the image



The image

Resolving limit, resolution

Resolving limit is the distance between two object details which can be just resolved as distinct objects (the smaller the better).

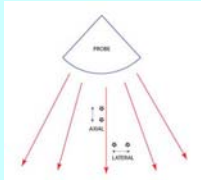
Resolution (resolving power): the reciprocal of the resolving limit (the greater the better)

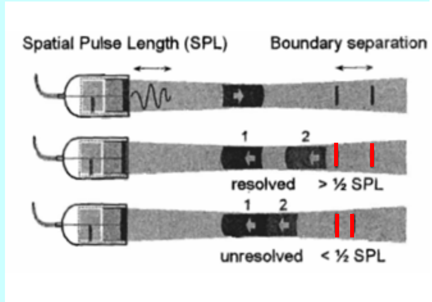
Lateral resolving limit - is the minimum separation of two I nterfaces aligned along a direction perpendicular to the ultrasound beam.

Resolving limit, resolution

Axial resolving limit - is the minimum separation of two interfaces aligned along the ultrasound beam.

Achieving good axial resolution requires that the returning echoes be distinct without overlap



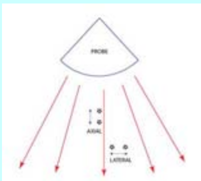


The minimal required separation distance between two boundaries is ½ SPL (about ½ λ) to avoid overlap of returning echoes

SPF inversely proportional to f

Resolving limit, resolution

Lateral resolving limit - is the minimum separation of two interfaces aligned along a direction perpendicular to the ultrasound beam determined by beam width, beam density and axial position of the object.

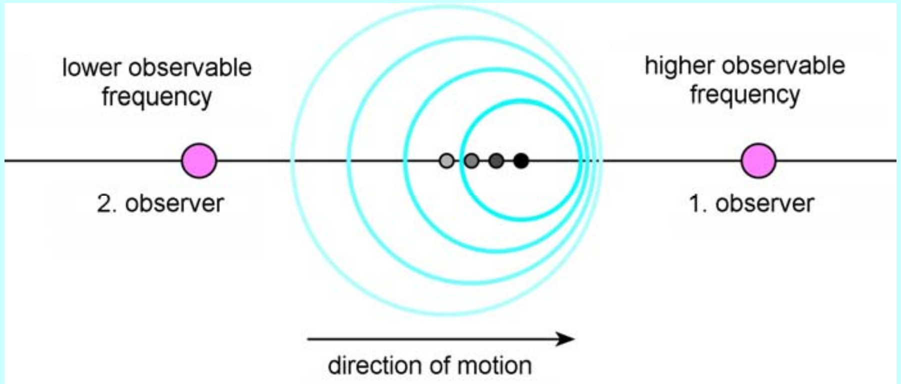


Typical values

frequency (MHz):	2	15
wavelength (mm):	0.78	0.1
penetration (cm):	12	1.6
lateral limit (mm):	3.0	0.4
axial limit (mm):	0.8	0.15

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)

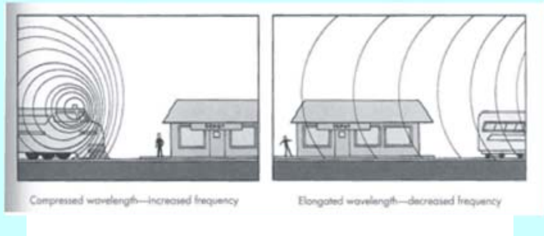


Teextbook Fig. VIII.39

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)

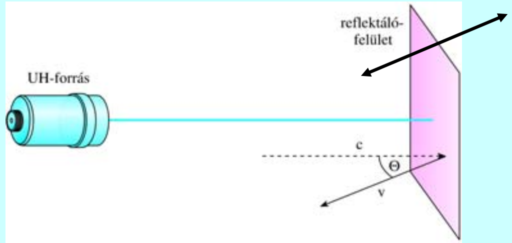
Moving source



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

f : initial frequency
f’: altered frequency
v: speed of source
c: speed of US

Moving reflecting object (surface),



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

Doppler-shift $f_D = f' - f_0$

Doppler shift is proportional to the speed of reflecting surface

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:

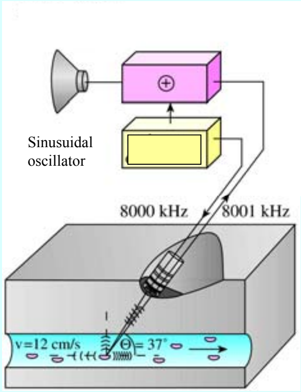
$$\Delta f = f_D = \pm \frac{v_i}{c} f$$

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 $\Theta = 90°$, $f_D = 0$)

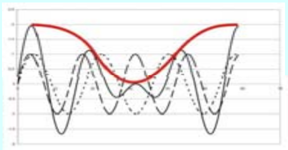
1-dimensional Doppler apparatus for measuring average flow velocity.



CW: continuous wave

source and detector are separated

Red blood cells as sound scatterers.

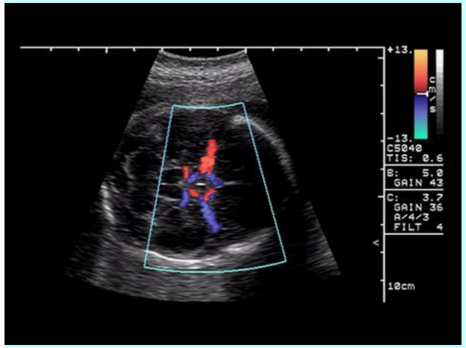


difference signal 1 kHz

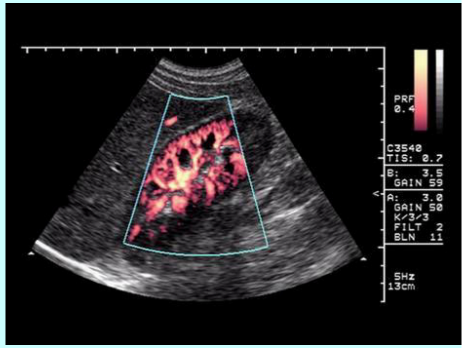
Tkv. VIII.41. ábra

Colour coding

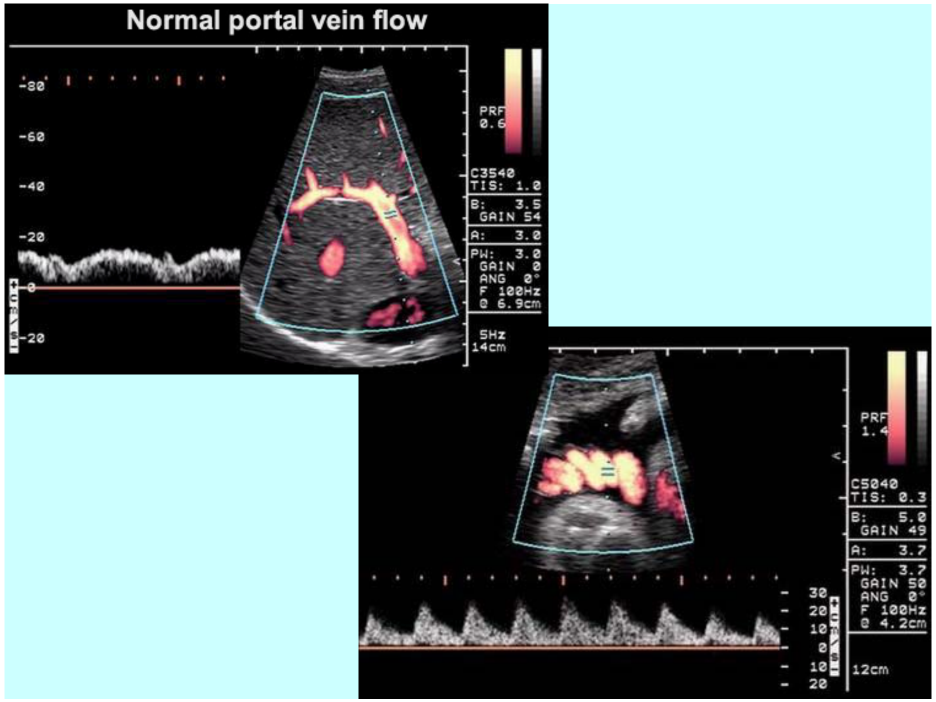
towards the transducer: warm colours
away from the transducer: cold colours



BART: Blue Away Red Towards



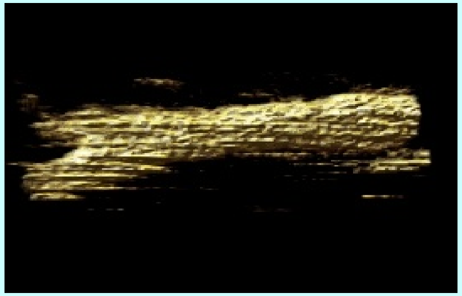
power Doppler



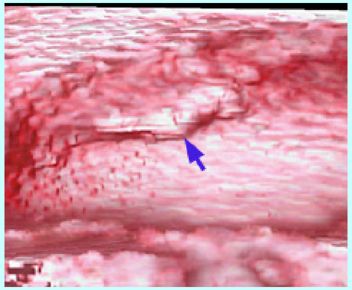
Reconstruction of the face of a fetus

3D reconstruction

carotis



bladder



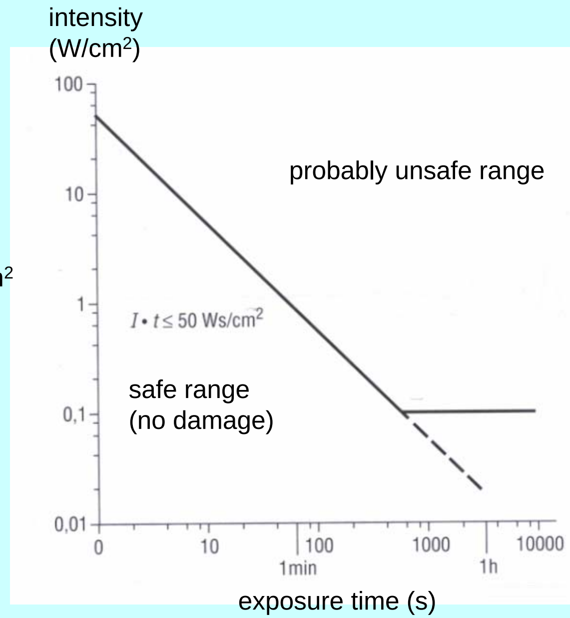
Safety

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



Question of the week

What does Doppler-shift mean?

Related chapters

Damjanovich, Fidy, Szöllősi: Orvosi Biofizika

II. 2.4.
VIII. 4.2.