ULTRASOUND

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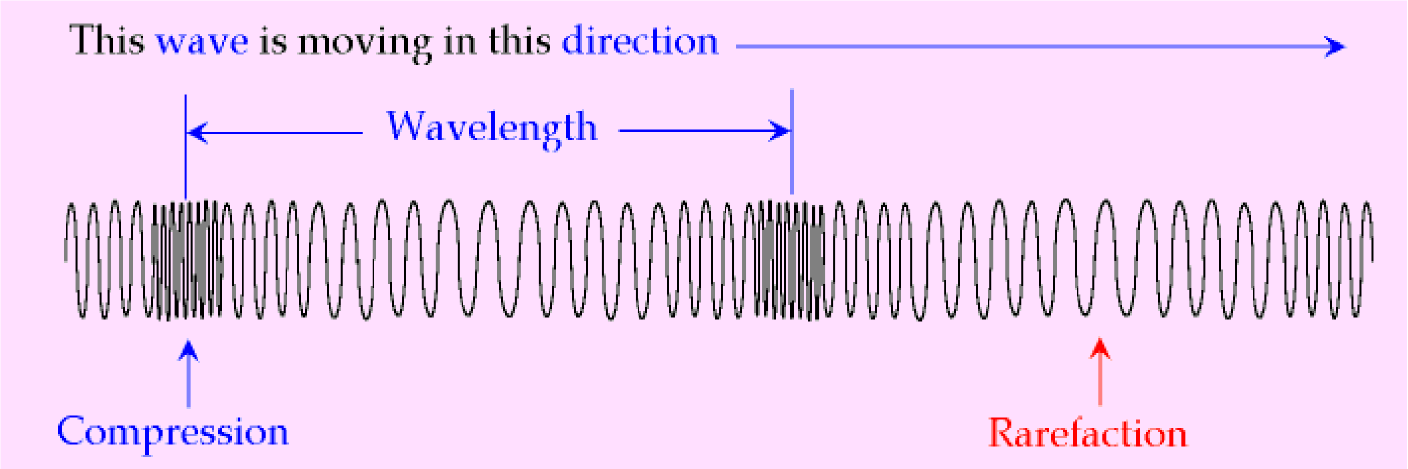
- The sound frequencies above **20000 Hz** are called "*ULTRASOUND*".

- 20000 Hz is the upper limit of audible sound in humans.

- Sound wave velocity in H_2O is similar to that in soft tissue.

- Sound waves are **longitudinal** waves.

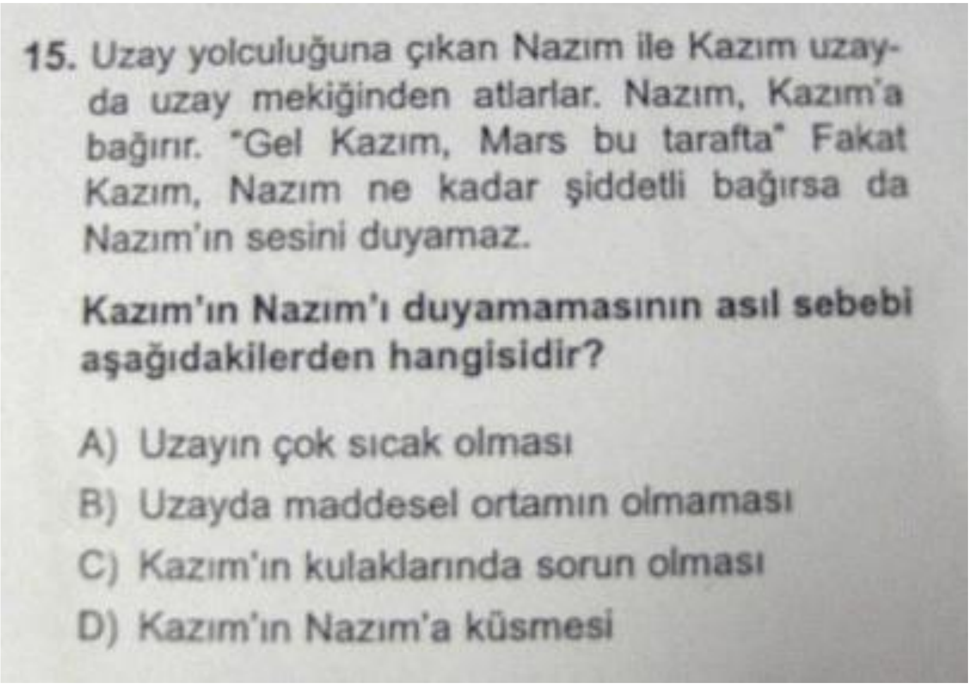


p.s1: Longitudinal waves: The direction of wave and oscillation of wave are parallel

p.s2: decompression: rarefaction are regions of reduced pressure

- Sound is formed by the compression and decompression of molecules.

❖ **Matter is needed to form a sound.**



15. Uzay yolculuğuna çıkan Nazım ile Kazım uzayda uzay mekiğinden atlarlar. Nazım, Kazım'a bağırır. "Gel Kazım, Mars bu tarafta" Fakat Kazım, Nazım ne kadar şiddetli bağırsa da Nazım'ın sesini duyamaz.

Kazım'ın Nazım'ı duyamamasının asıl sebebi aşağıdakilerden hangisidir?

A) Uzayın çok sıcak olması

B) Uzayda maddesel ortamın olmaması

C) Kazım'ın kulaklarında sorun olması

D) Kazım'ın Nazım'a küsmesi

Characterization of ultrasound waves;

like all waves

- Frequence
- Wavelength
- Period (time) (1/f)
- Velocity = Frequency x wavelength

Velocity = frequency x wavelength

$$v = \lambda . f$$

- **It is determined by the medium.**

❖ **The higher density results in the higher velocity.**

Example

- A pulsed sound signal is transmitted through soft tissue interface and reflected back in 60μsec. How deep is the reflecting surface?

(sound velocity in soft tissues = 1540m/s)

Depth = velocity x ½ time

= 1540m/s x ½ 60x10^{-6}s

= 4.6cm

Ultrasound Waves in Medicine

Diagnostic sonography (ultrasonography) is an ultrasound-based diagnostic imaging technique used for visualizing subcutaneous body structures including tendons, muscles, joints, vessels and internal organs for possible pathology or lesions.

It has been used since 1950s **(1-20 MHz)**

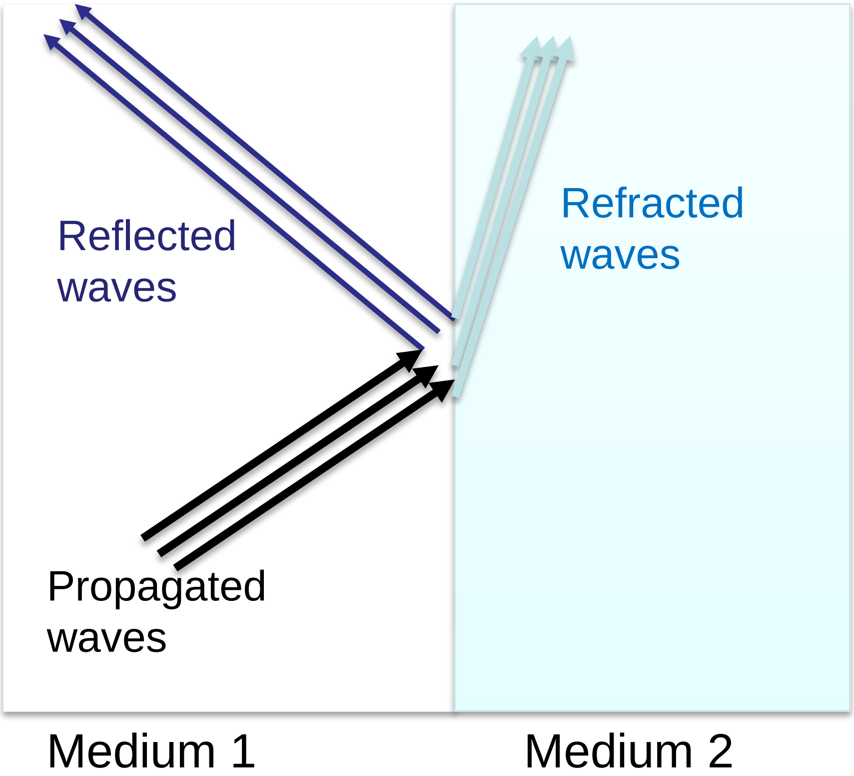
How sound waves travel through a medium is measured by its **“impedance”.**

Impedance (Z) = density x velocity

Acoustic impedance is considered in terms of density.

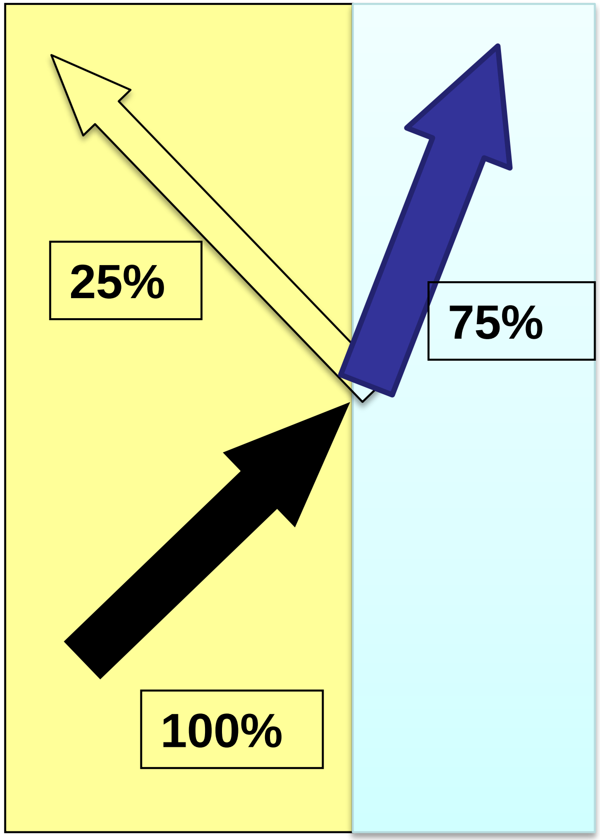
A density change will cause reflection or refraction at interfaces having different densities.

- **It is very important because largest reflections occur between tissues with great differences in acoustic impedance.**



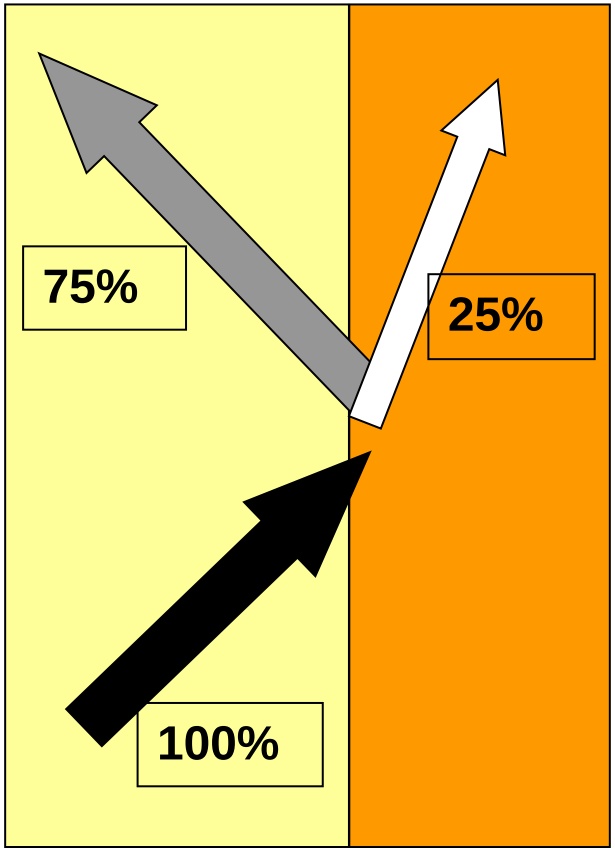
Ultrasound is reflected and refracted by an interface between two medium of different acuostic impedance

❖ ***Diagnostic ultrasound imaging is based on the principle that ultrasound is reflected at interfaces of two medium having different densities.***



The amounth of ultrasound reflected or refracted depends upon the angle at which the ultrasonic beam hits the interface between different medium.

As the angle approaches 90º, a higher percentage of the sound reflected.



❖**The amount reflected depends on difference in density and angle of incidence.**

- Whether or not reflection occurs depends on relative size of object with respect to **wavelength.**
- Size of object must be at least **¼ of the wavelength (λ)**
- Ultrasound with higher frequency **(lower λ)** can reflect smaller objects.

"i.e. a high frequency ultrasound beam has a greater resolving power (i.e. resolution)"

Frequency

- Diagnostic ultrasound is identified by its frequency of operation.

<u>As frequency increases,</u>

✓Ability to resolve smaller objects increases.
✓Penetration in tissue decreases.
✓The beam becomes more collimated.

However we cannot increase the frequency of ultrasound waves as we like.

!! The penetration problem!!

- ***As frequency increases "attenuation" of the beam increases and penetration decreases.***

Attenuation = absorption + refraction + scattering

- ***The frequency increases* → *The absorption increases* → *Thus less energy is transmitted to deeper tissues.***

Desibel –dB-

- The decibel (**dB**) is used to measure sound level.
- The dB is a logarithmic unit used to describe a ratio.
- Decibel is a relative and logarithmic unit.
- Desibel is a relative measure used to compare relative intensities of two ultrasound beams .i.e. transmitted and reflected beams.

$dB = 10 \log (I_r / I_t)$

I_r- reflected wave, I_t-transmitted wave

Example

- If the reflected ultrasound beam is 100 times less intense than the transmitted beam :

$$dB = 10 \log (I_r / I_t) = 10 \log 1/100 = 10 (-2) = -20 \text{ dB}$$

"An amplification gain of 20dB must be used to increase apparent size of reflected wave."

- In abdominal ultrasound a 40 dB loss is seen when imaging tissue 10 cm. deep

Instrumentation and Operation

- The basis of diagnostic ultrasound imaging is the transducer that converts one type of energy form to another type.
- In ultrasound ==== Piezoelectric Crystal

- Piezoelectric effect: Crystal contracts and expands according to the polarity of electric field and generates sound waves. When electric field oscillates at high frequency, piezoelectric crystal generates sound waves at high frequency.

When sound waves strike the crystal, the crystal oscillates to form electrical signals.

The intensity of these electrical signals is proportional to the intensity of the incoming wave.

❖ *Best image resolution is obtained at the near field far field transition interface.*

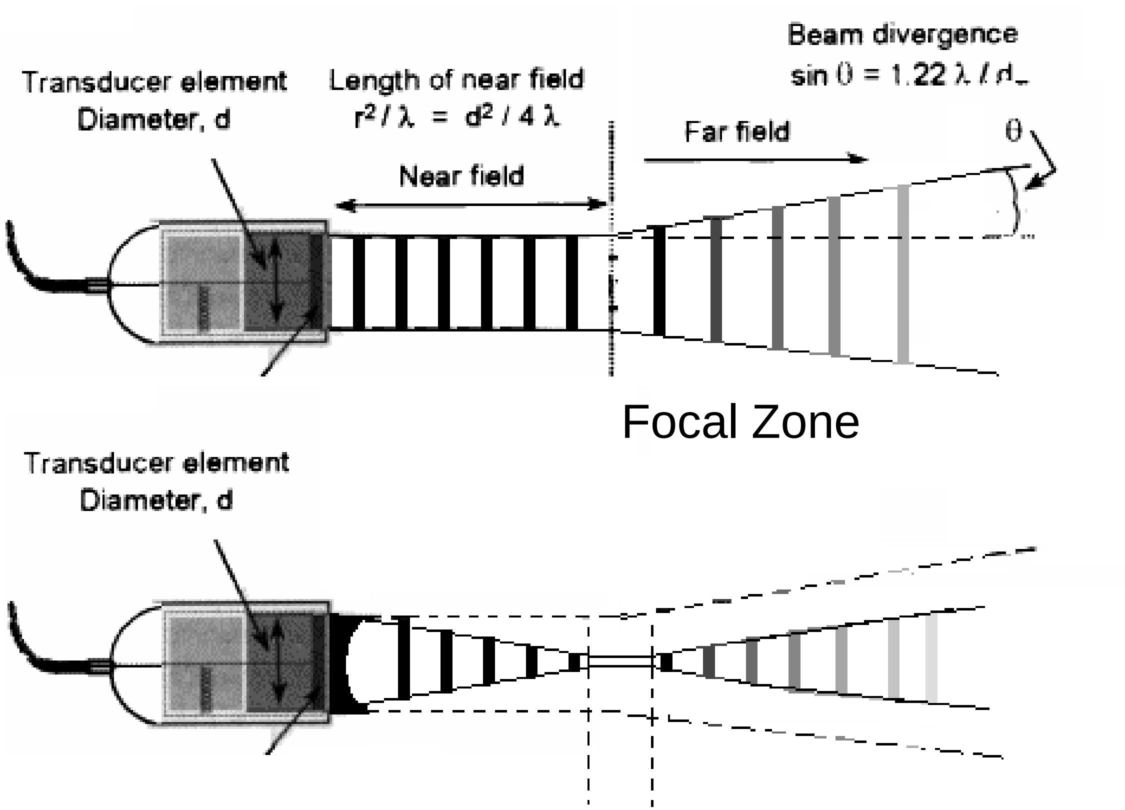


Diagram of ultrasonic beams emitted by an unfocused and a focused transducer

As beam propagates it is parallel (near field) then it begins to diverge (far field).

At near field the beam is highly collimated but intensity varies.

At far field beam diverges but intensity is uniform.

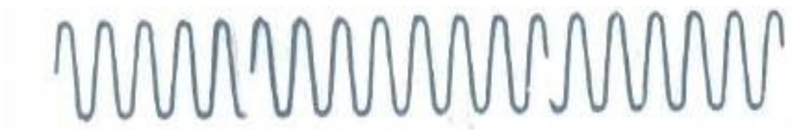
❖ ***The diameter and length of near field and divergence of far field is determined by transducer diameter and ultrasound frequency.***

*As diameter ↑ near field length ↑ far field divergence ↓

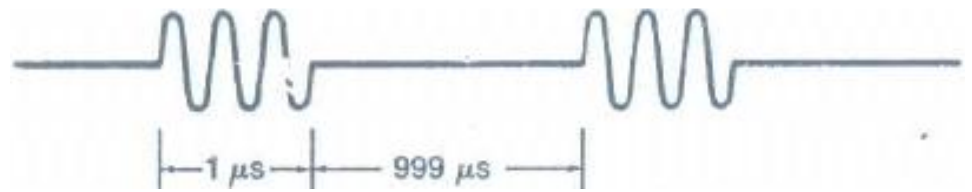
* As frequency ↑ near field length ↑ far field divergence ↓

Two types of ultrasound waves are used in diagnosis.

Continuous



Pulsed



To produce the continuous or pulsed waves depend on transducer.

<u>Continuous waves</u> :::: fetal heart and blood flow examinations in <u>Doppler ultrasound</u>

- Most ultrasound imaging is done with pulse-echo system
  - A-mode
  - B-mode
  - M-mode
  - real time

- Typically 1-5μs pulse given and 995-999μs detection.

Instrumentation

- **Instrument** Echograph
- **Transducer** Piezoelectric crystal
- **Transmitter** regulates sending the ultrasound beam by transducer.

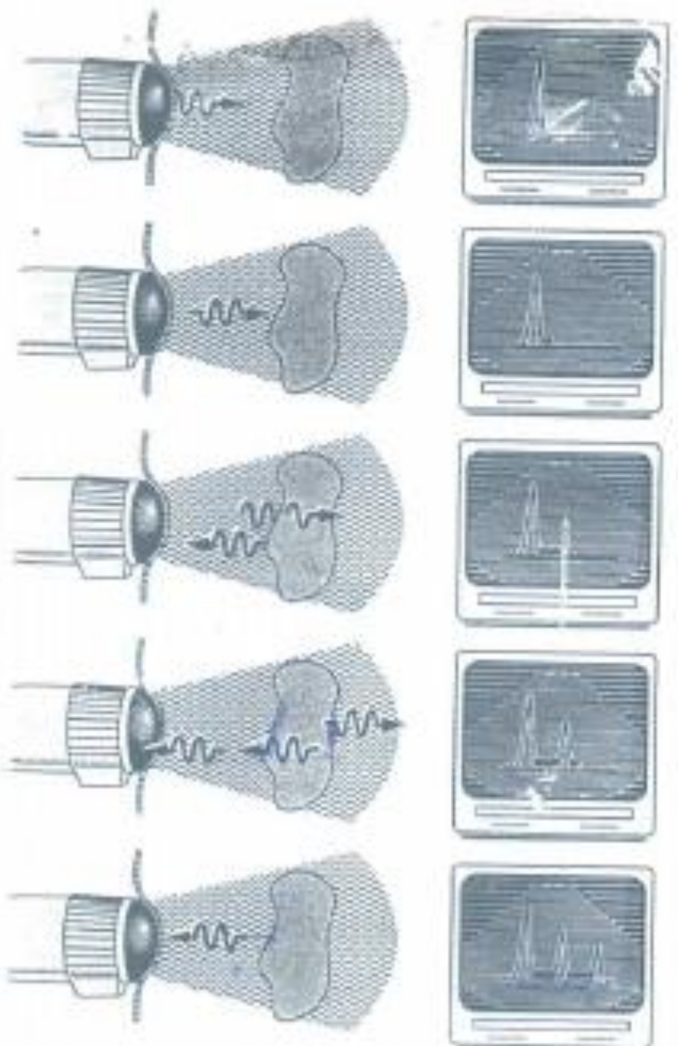
There is a timer which controls the duration and frequency of the beam.
Commercial diagnostic echographs have a **repetition rate** of 1000/sec.
i.e. beam is sent for 1μs and transducer functions as receiver for 999μs.

Operational Modes

- **<u>Static Imaging Modes</u>**
  - **A Mode** for midline shift of the brain
  - **B Mode** for abdominal imaging

- **Dinamic Imaging Modes**
  - **M Mode** for dinamic imaging of internal structures
  - **Real Time** for structures in motion
  - **Doppler Ultrasound** for blood flow and fetal heart beat measurements.

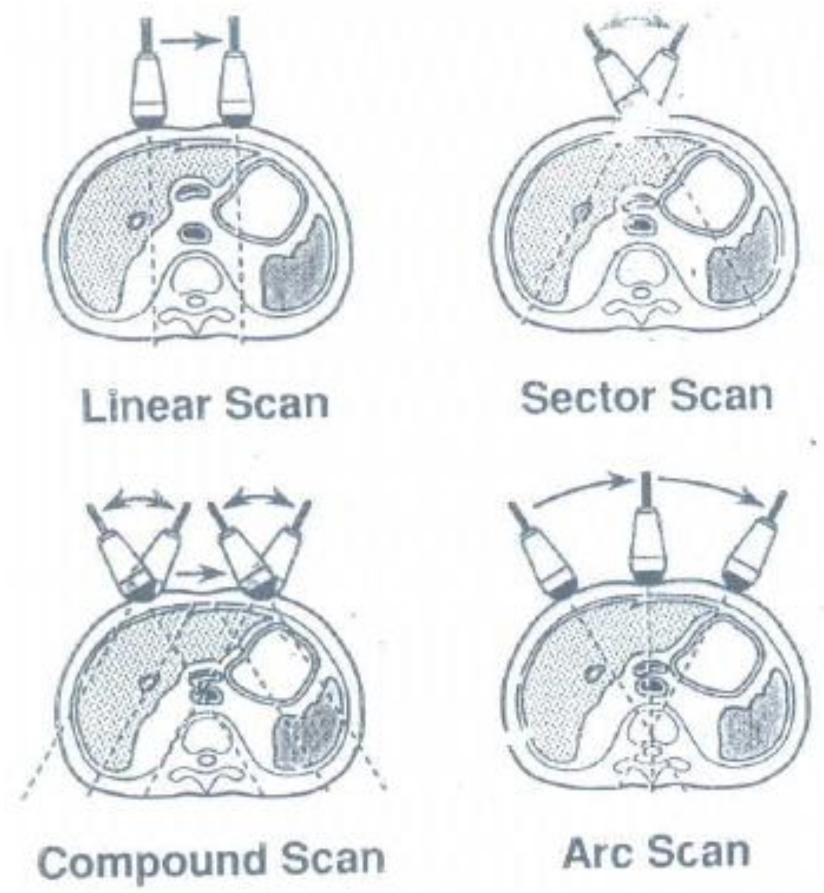
A-Mode Display – Amplitude Mode



- A mode was the first ultrasound machine. It didn't have ultrasound images, only a graph.

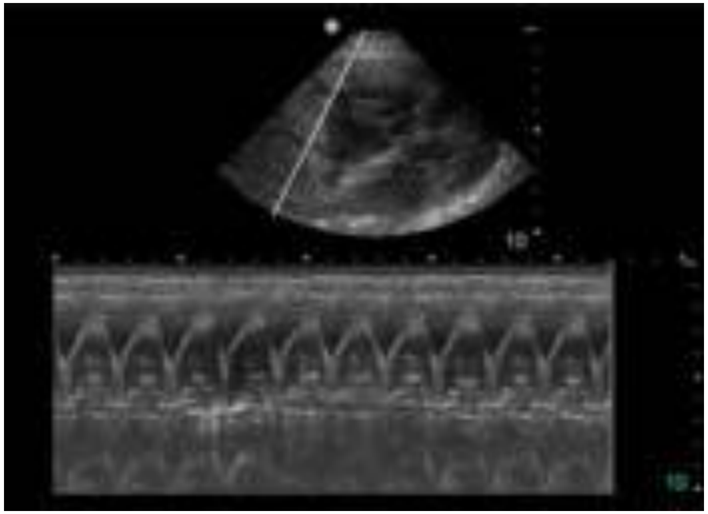
➢**Distal reflections produce smaller blips than proximal reflections.**

B-Mode Display- Brightness Mode



- The intensity of the reflected wave is displayed as a bright spot.
- The pulses are stored as the transducer is moved about the body.
- Summing all the pulses forms an image.

M-Mode – Motion Mode



•Captures returning echoes in only one line of the B-mode image and display them over a time axis.

•This type of ultrasound is principally used for monitoring the heart and is called echocardiography.

•It can be synchronized with E.C.G. for better evaluation of cardiac functions.

Real-Time Imaging

Advantages (B-Mode)

- Low cost
- Image does not depend on operator skill.
- Less time required

Disadvantages (B-Mode)

- Lateral resolution less than B-mode.

❖Transducer is moved over surface of the patient.

❖Pulses are stored and image is formed.

Doppler Ultrasound

- ***Doppler effect:*** Wavelength (frequency) changes according to relative motion of source and receiver.
- A continuous wave is emitted in Doppler applications.
- When transducer receives the reflected beam, the change in frequency caused by Doppler effect is electronically detected.

- Velocity distribution of tissue (blood) is visualized
- In Doppler ultrasound the targets are red blood cells.
- Doppler is used to monitor fetal heart beat and blood flow in the heart.
- By measuring the change in frequency velocity of blood and therefore pressure of the blood in the arteries can also be determined (Doppler echo).

DOPPLER IMAGING
Measures speed of blood in parallel direction (to scan line)

- Doppler ultrasound
  - Based on shift in frequency in an US wave caused by a moving reflector (blood cells)
  - Objects moving toward the transducer - higher frequency and shorter wavelength
  - Objects moving away from the transducer - lower frequency and longer wavelength
  - If object moving perpendicular to the transducer, no change in the observed frequency or wavelength

- **Measures the Doppler frequency shift between the transducer and the red blood cells**
- **Higher frequency = blood toward transducer**
- **Lower frequency = blood away from transducer**

DOPPLER SHIFT
"Because of the speed of the blood, speed of the reflected sound waves change"
means
"increased or decreased frequency of the reflected sound waves"

Example / Monitoring fetal heart beat

If transmitting frequency is 2MHz ,the velocity of sound v=1540m/s and velocity of interface μ=20 cm/s what is the Doppler shift?

(Fx 2μ) / v = 2 MHz (2x20cm/s) / 1540m/s

= 519 Hz

This value is in the audible range so you can actually hear the heart beat.

This is called " **ultrasound stethoscope"**.

AXIAL RESOLUTION

❑To resolve closely separated interfaces that lie on the axis of the ultrasound beam.

❑Depends on length of ultrasound pulse.

❑ For optimum axial resolution highes frequency possible must be used.

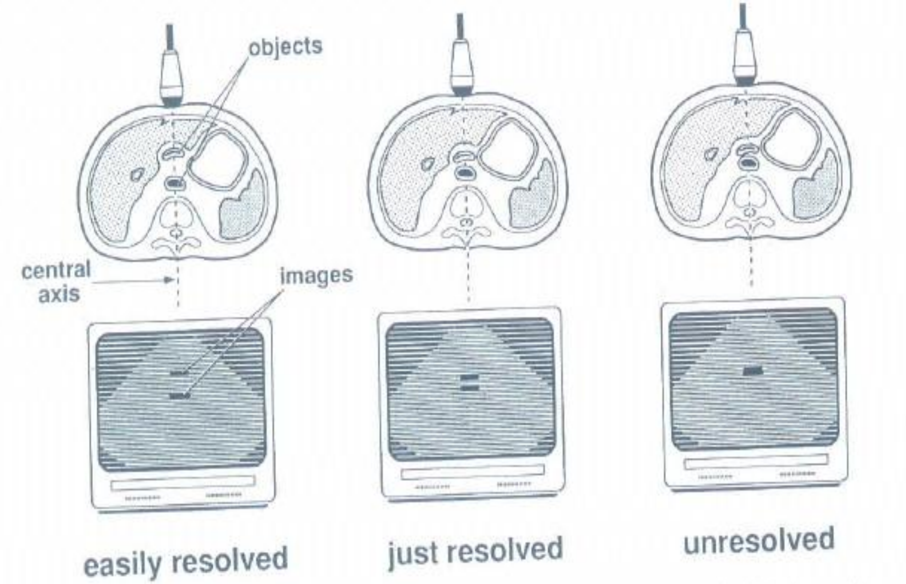


Fig. 29-8. Axial resolution is the ability to resolve closely separated objects or interfaces on the axis of the ultrasound beam.

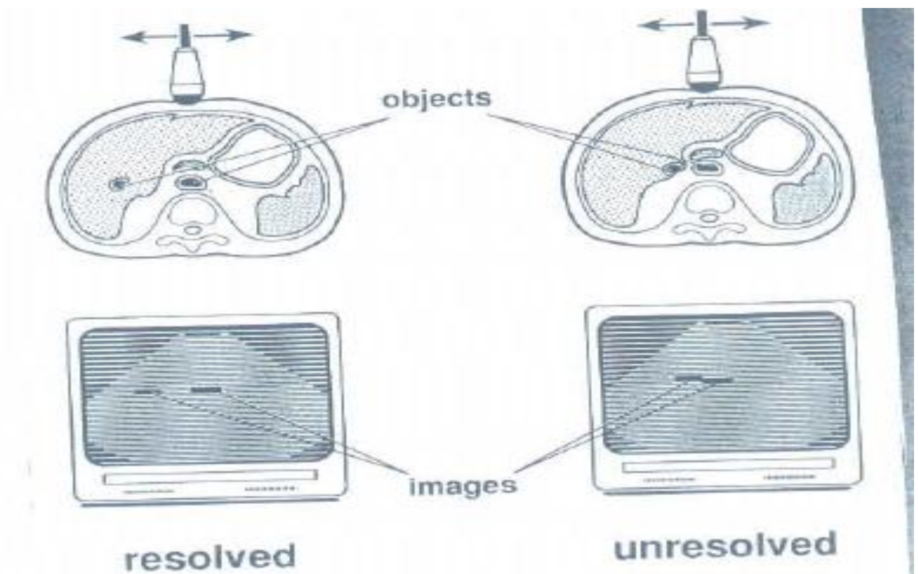


Fig. 29-9. Lateral resolution measures the ability of the ultrasound system to detect closely separated objects lying in a plane perpendicular to the beam axis.

LATERAL RESOLUTION

❑Resolution in plane perpendicular to axis of beam.

❑ It is approximately equal to effective beam width

❑The smaller the size of transducer the better the lateral resolution

❑ The higher the frequency the better the lateral resolution

** Lateral resolution is more important for image quality.

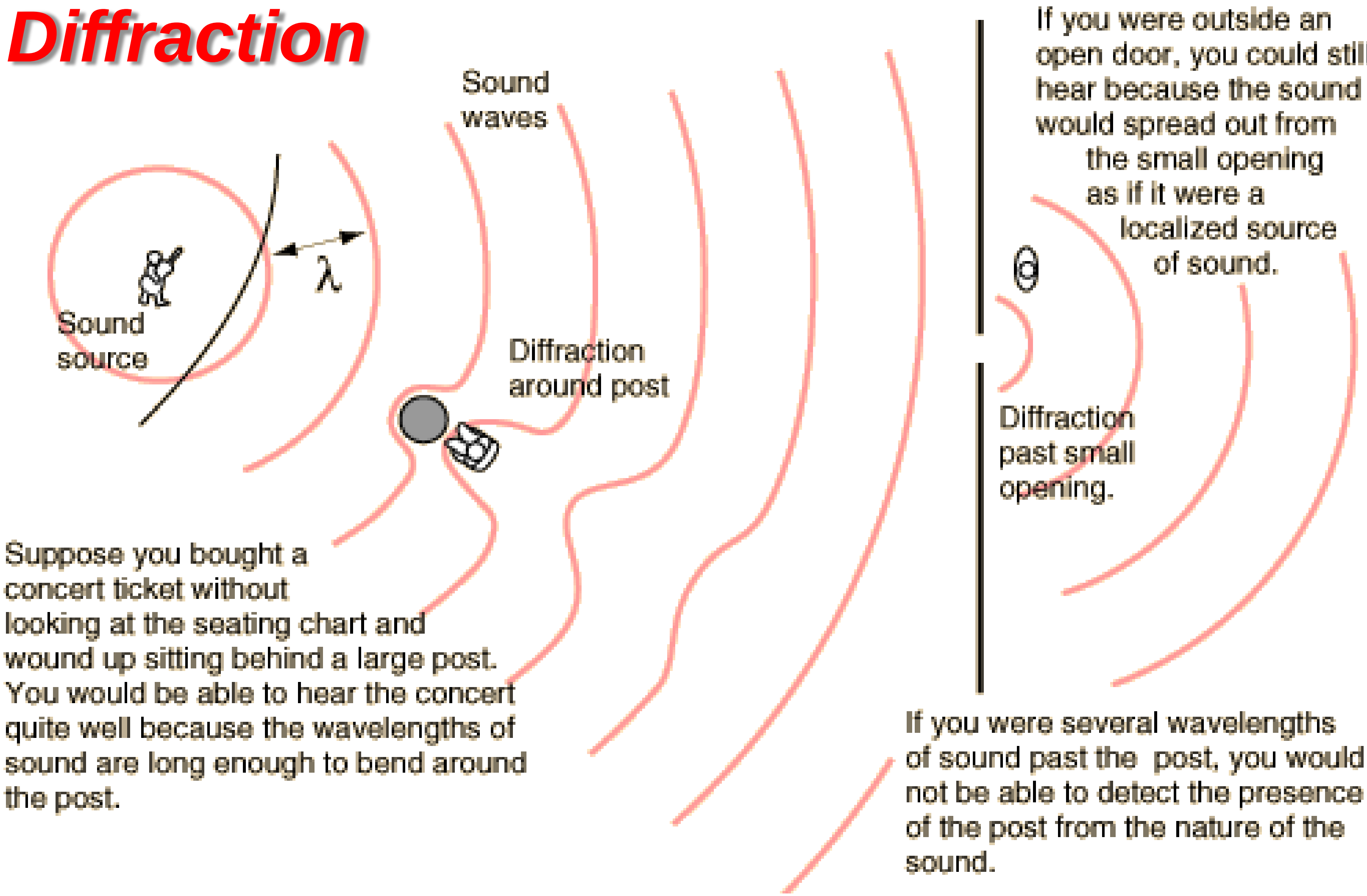
We do not use very strong pulses in USG, WHY?

. Ultrasound at high energy can be used to ablate (kill) tissue.

.

. Temperature increase is limited to 1º C for safety.

Diffraction



P.S: *Diffraction of sound:* The bending of waves around small obstacle and the spreading out of waves beyond small opening.