MEDICAL PHYSICS

Ultrasound in medicine

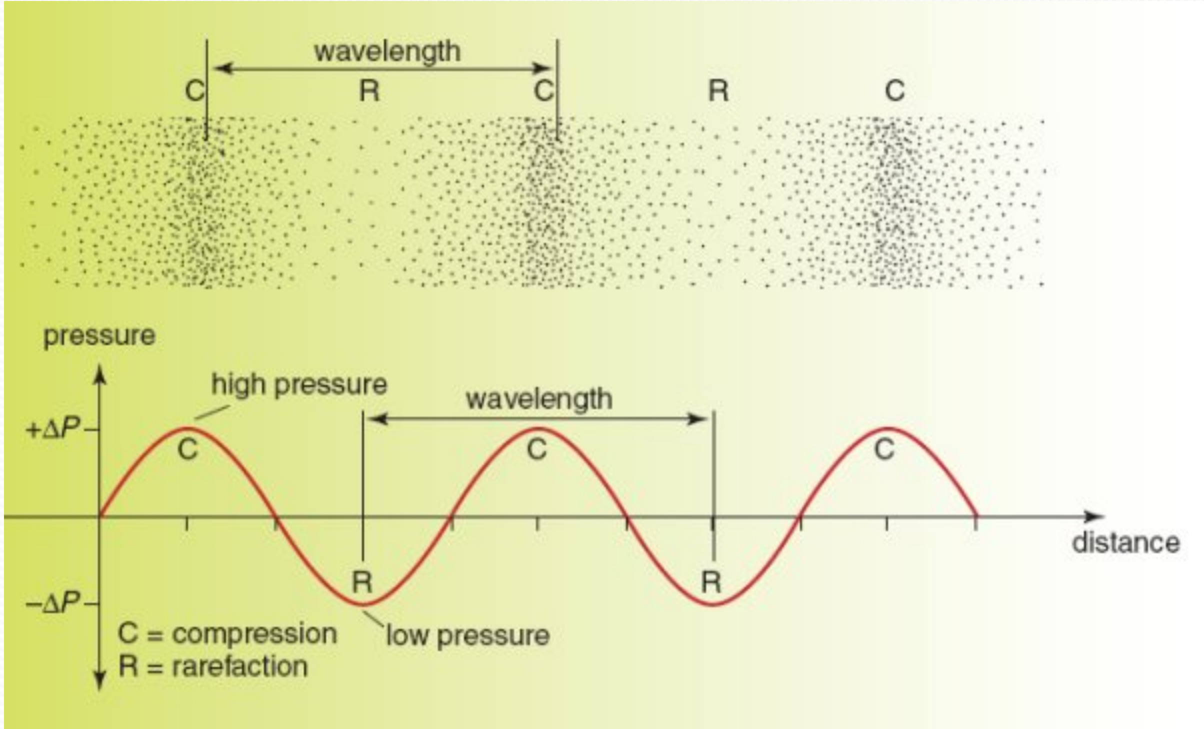
9702 A-Level

Rajan Swor Rai

Ultrasound

Sounds above the audible frequency range for humans

- Longitudinal waves that cause particles to oscillate back and forth and produce a series of compressions and rarefactions.
- Audible Frequency Range: 20 Hz-20 KHz
- f > 20 KHz can be taken as Ultrasound



Ultrasound - biomedical applications

non-invasive imaging, used to detect distances, depths and for medical purposes

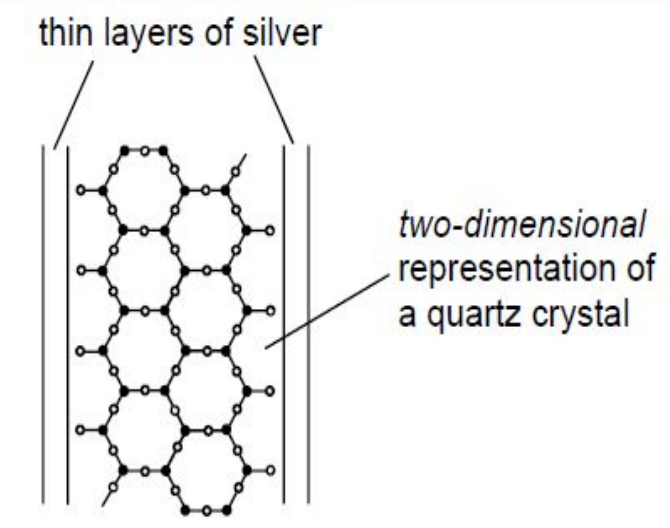
- heart and blood vessels, incl. the abdominal aorta and its major branches
- liver
- gallbladder
- spleen
- pancreas
- kidneys
- bladder
- uterus, ovaries, and unborn child (fetus) in pregnant patients
- eyes
- thyroid and parathyroid glands
- scrotum (testicles)

Piezo-electricity

- derived from the Greek word *piezo* ,which means to *squeeze* or *press*
- *piezoelectricity* means electricity resulting from pressure
- many materials, both natural and synthetic, exhibit piezoelectricity
- certain crystals such as Langasite ($La_3Ga_5SiO_{14}$), Gallium orthophosphate ($GaPO_4$),ceramics such as *lead zirconate titanate,and* biological matter such as *bone*, DNA and various proteins

Generation of Ultrasound (1)

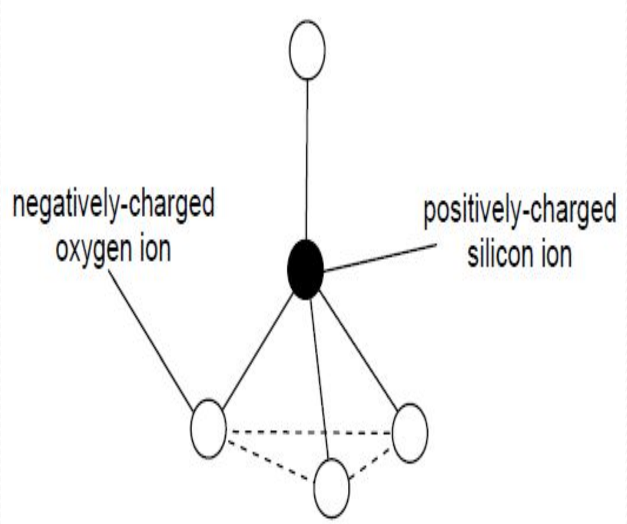
- Ultrasound can be generated using a *piezo-electric* Transducer
- *Transducer*- device that converts energy from one form to another
- Piez0-electric crystal, such as *Quartz* converts electrical energy into Ultrasound energy

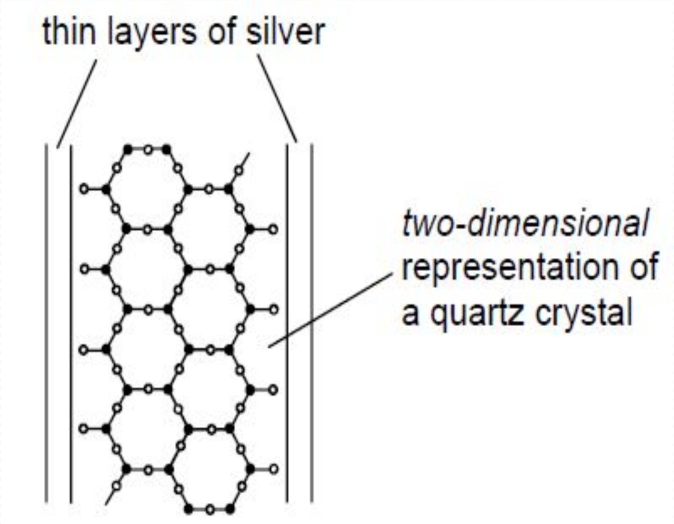


Structure of Quartz

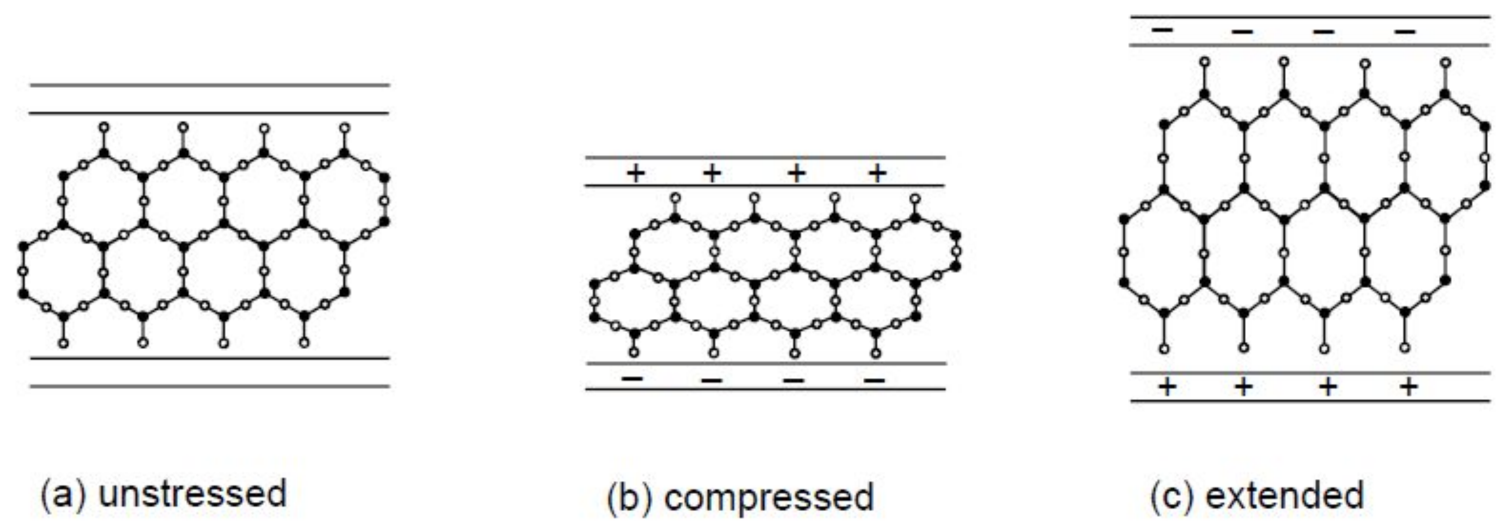
- Quartz –a complex structure

  -Silicate
- Large no. of repeating tetrahedral Silicate units
- -vely charged oxygen ions are not rigidly fixed in the lattice
- Movement can be encouraged by applying an electric field.





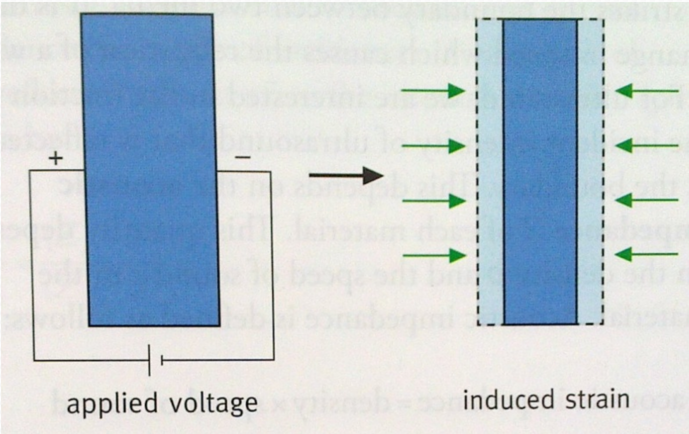
Generation of Ultrasound (2)



- When unstressed, centers of charge of the +ve & -ve ions in the lattice coincide-effects are hence neutralized.
- When a voltage is applied in one direction, it shrinks slightly (thinner) as a result of redistribution of charge
- When the voltage is reversed, it expands slightly (thicker)
- Alternating voltage with frequency ‘f’ sets up mechanical vibration in the crystal
- Resonance occurs ,if the frequency of the applied voltage is same as the natural frequency of vibration of crystal, and hence will have max. amplitude
- Frequency of the oscillation produced is Ultrasonic range (> 20KHz), thus producing UltraSonic sound.

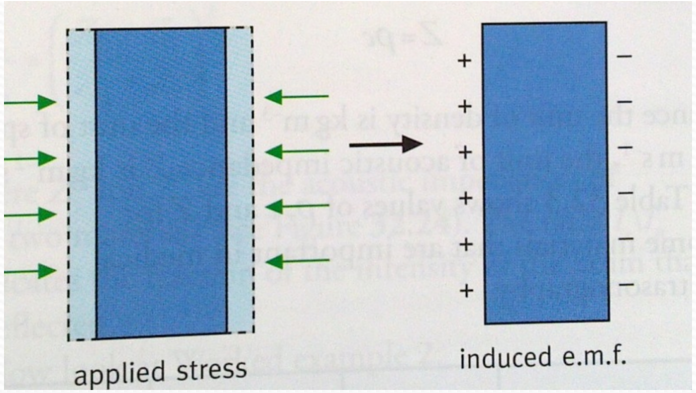
Piezoelectric crystal as Transducer & Receiver

- Alternating voltage sets up mechanical vibration having frequency equal to that of Ultrasound in the Quartz crystal

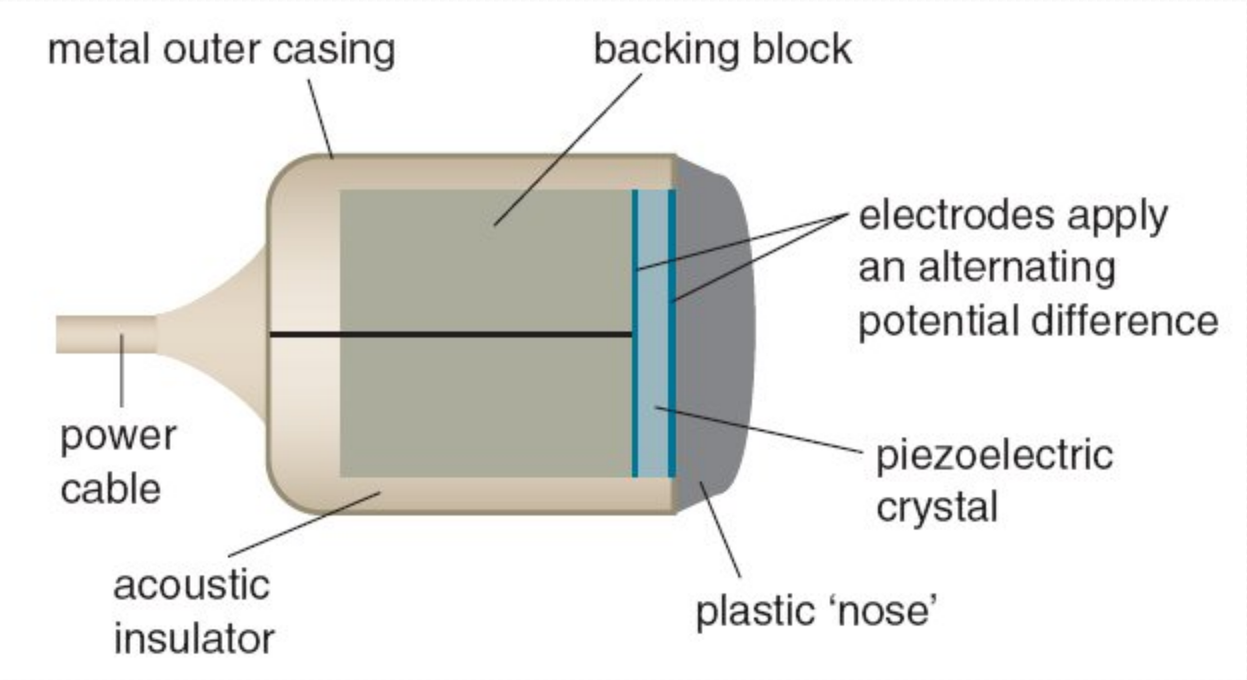


- Ultrasonic Transducer can also be used as receiver

- Ultrasonic wave incident (in the form of stress) on the Piezo-electric crystal causes an induced e.m.f. across the crystal because the ultrasound wave makes the crystal distorted so that the redistribution of charge inside the crystal takes place



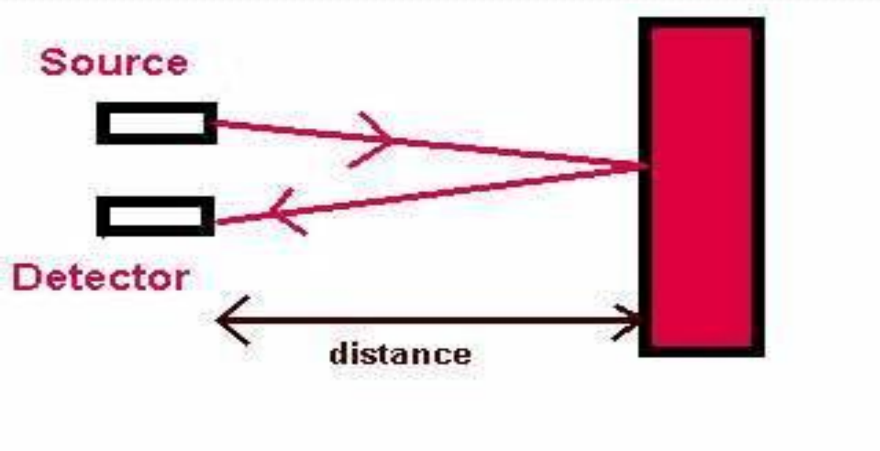
Simplified diagram of a typical Piezo-electric Transducer/Receiver



Ultrasound – how does it work?

- the same principles involved in the **sonar** used by bats, ships and fishermen
- when a sound wave (frequency **2.0 to 10.0** megahertz) strikes an object, it **bounces backward or echoes**
- by measuring these **echo waves** it is possible to determine how **far away** the object is and its **size, shape, consistency** (solid, filled with fluid, or both) and uniformity.
- a **transducer** **both sends the sound waves and records/detects the echoing waves**
- When the transducer is pressed against the skin, it directs a stream of *inaudible, high-frequency sound* waves into the body. As the sound waves bounce off internal organs, fluids and tissues, the sensitive microphone in the transducer **records tiny changes in the sound's pitch and direction**. These signature waves are instantly measured and displayed by a computer, which in turn creates a **real-time picture on the monitor**

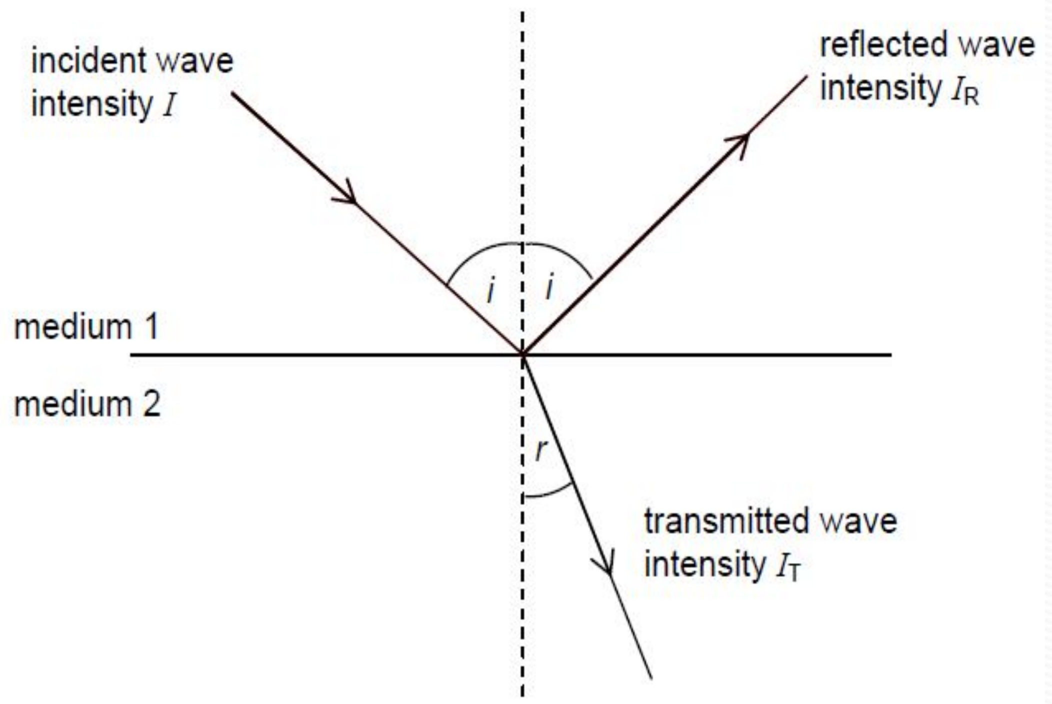
Principle of use of Ultrasound Scan



- Ultrasound waves are directed into the body
- The waves pass through various tissues and
- Partially reflected at each boundary where the wave speed changes
- The reflected waves are then detected, and transformed into voltage pulses
- These voltage pulses can be amplified if necessary and processed to construct an internal image of the body on CRO or computer screen

Reflection & Transmission of Ultrasound

- A beam of ultrasound when reaches a boundary between two different media
- The beam is partially refracted (so that the transmitted beam has changed direction)
- And partially reflected



For an incident intensity I, reflected intensity I_R and transmitted intensity I_T, then from energy considerations,

$$I = I_R + I_T.$$

Acoustic Impedance & Intensity Reflection Coefficient

For any medium, a quantity known as the *specific acoustic impedance* Z is defined as

$$Z = \rho c,$$

where c is the speed of the wave in the medium of density ρ. When a wave is incident normally on a boundary between two media having specific acoustic impedances of Z_1 and Z_2, the ratio I_R / I of the reflected intensity to the incident intensity is given by the expression

$$\frac{I_R}{I} = \frac{(Z_2 - Z_1)^2}{(Z_2 + Z_1)^2}$$

The ratio I_R / I is known as the *intensity reflection coefficient* for the boundary and is usually given the symbol α. Clearly, the value of α depends on the difference between the specific acoustic impedances of the media on each side of the boundary. Some approximate values of specific acoustic impedance Z

medium	$Z = \rho c$ / kg m^{-2} s^{-1}
air	430
quartz	1.52×10^7
water	1.50×10^6
blood	1.59×10^6
fat	1.38×10^6
muscle	1.70×10^6
soft tissue	1.63×10^6
bone	$(5.6 - 7.8) \times 10^6$

What is meant by Intensity Reflection Coefficient?

- At air-tissue boundary, a very large fraction (α ≈ 99.95%) of the incident ultrasound will be reflected

- At tissue-bone boundary, a large fraction (α ≈ 33%) will be reflected

- Patient's skin is in contact with air; so 99.95% of the ultrasound will be reflected before entering the body

- At a boundary between soft tissues including fat and muscles , very little (α ≈ very small) will be reflected

Impedance Matching

- Patient's skin is in contact with air; so 99.95% of the ultrasound will be reflected before entering the body

- Air between transducer and skin interrupts smooth transmission of ultrasound into the body

- No air is desired to be trapped between transducer and skin

- To overcome this problem
  - the transducer is *coupled* to the skin using a 'gel' whose impedance ($Z = \rho c$) matches to that of the skin

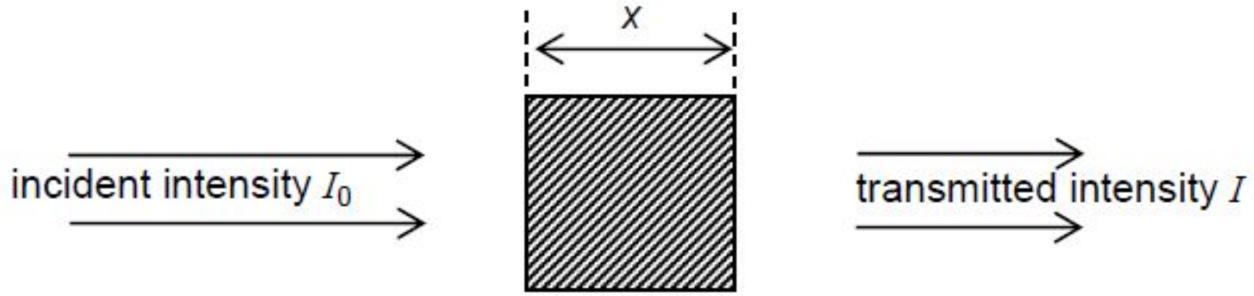
  ⇒ Impedance Matching
- Typically,

  -Z for 'gel' is $1.65x10^6$ $Kgm^{-2}s^{-1}$

  -Z for 'skin' is $1.7x10^6$ $Kgm^{-2}s^{-1}$

  ⇒with gel between the skin and the transducer, percentage of reflected intensity is just 0.03%
- ✔ The gel reduces the size of the impedance change between boundaries at the skin and thus reduces reflection at the skin

Absorption Coefficient



The intensity I of the beam after passing through the medium is related to the incident intensity by the expression

$$I = I_0 e^{-kx},$$

where k is a constant for the medium referred to as the *absorption coefficient*.

medium	absorption coefficient / m^{-1}
air	120
water	0.02
muscle	23
bone	130

How the depth of reflecting tissues is accessed?

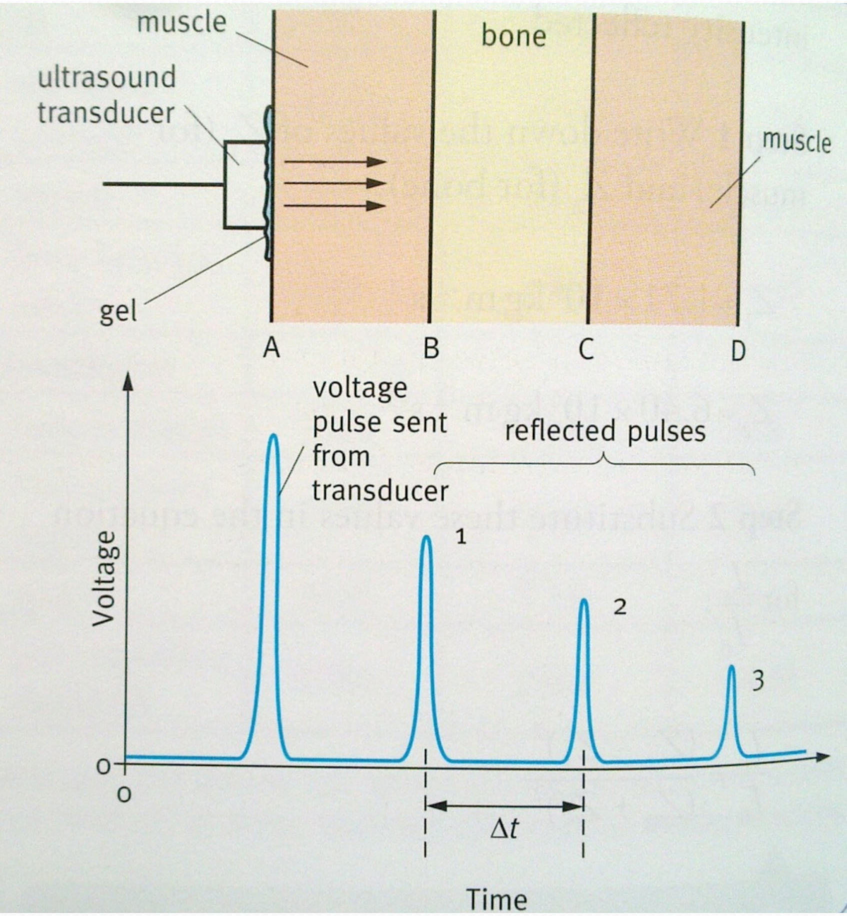
A-Scan

the Simplest Scan

- A pulse of ultrasound is sent into the body and the reflected 'echos' are detected and displayed on an oscilloscope or computer screen as a voltage-time graph

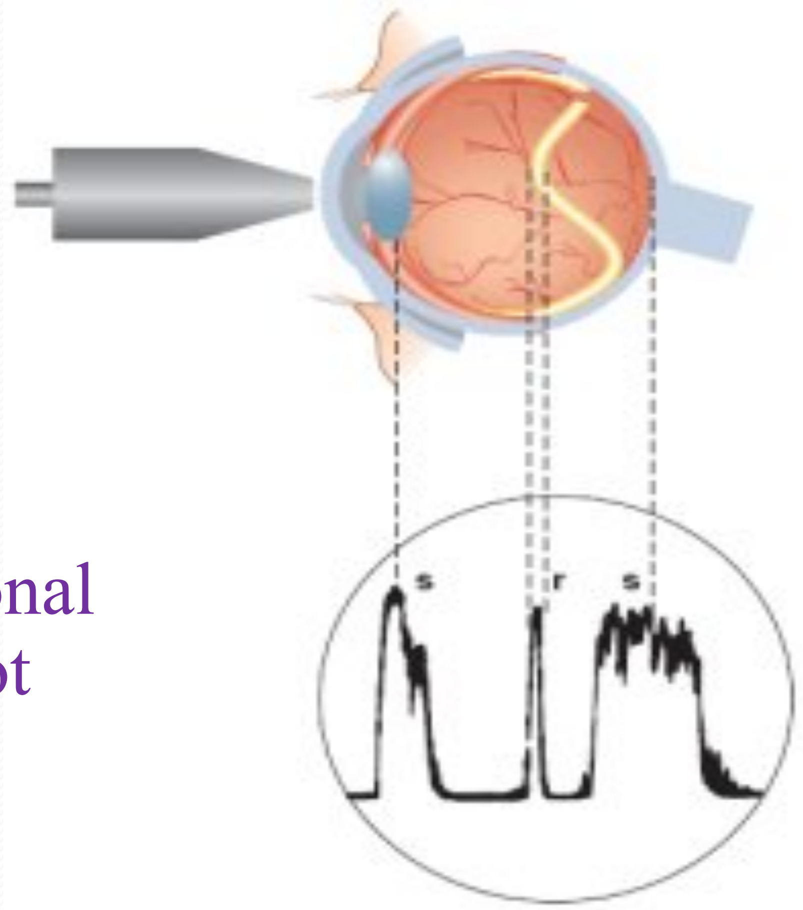
-Each partial reflection of the ultrasound is detected and appears as a spike on the screen

-'Echos' from tissues deeper in the body are weaker because ultrasounds are gradually attenuated as they pass through the body



A-Scan(II)

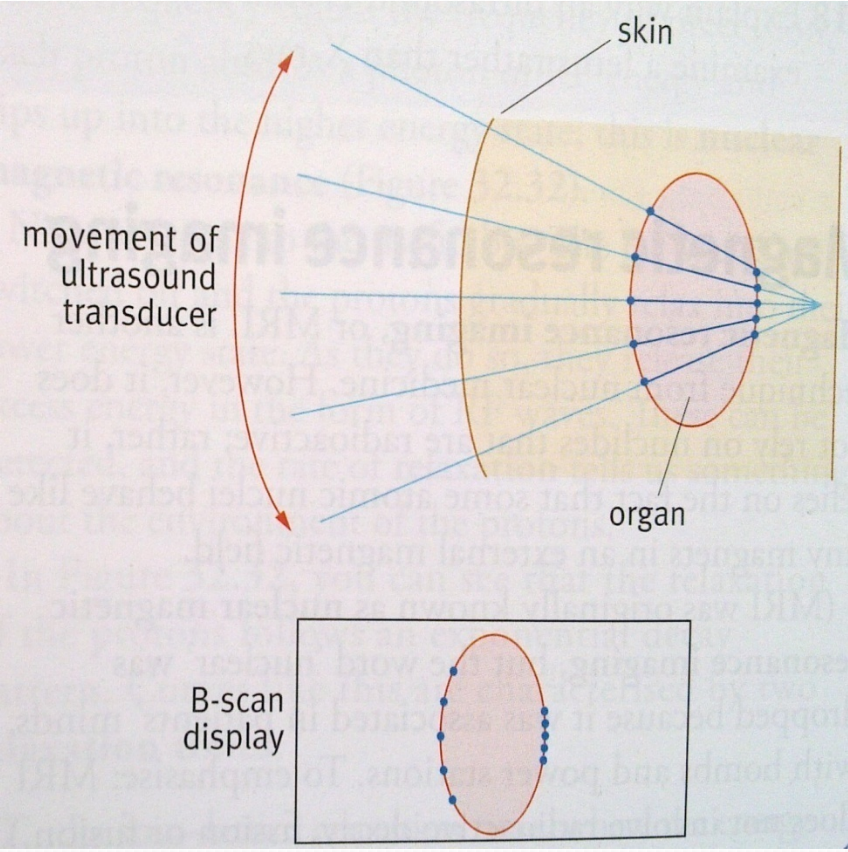
- Each partial reflection of the ultrasound is detected and appears as a spike on the screen



- A-scans only give one-dimensional information and therefore are not useful for imaging.

B-Scan(I)

- 2-D image is formed from a series of A-scans, taken from a range of different angles
- Each reflected pulse is shown as a bright dot to represent the position of reflecting surfaces
- By moving the transducer, a series of dots on the screen trace out the shape of the organ being examined

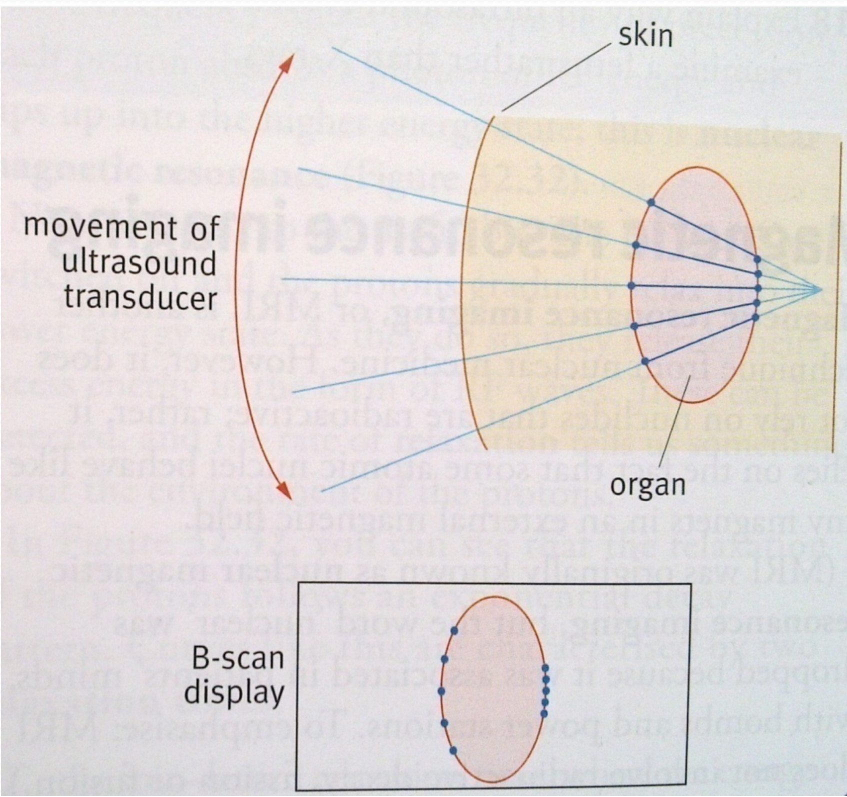


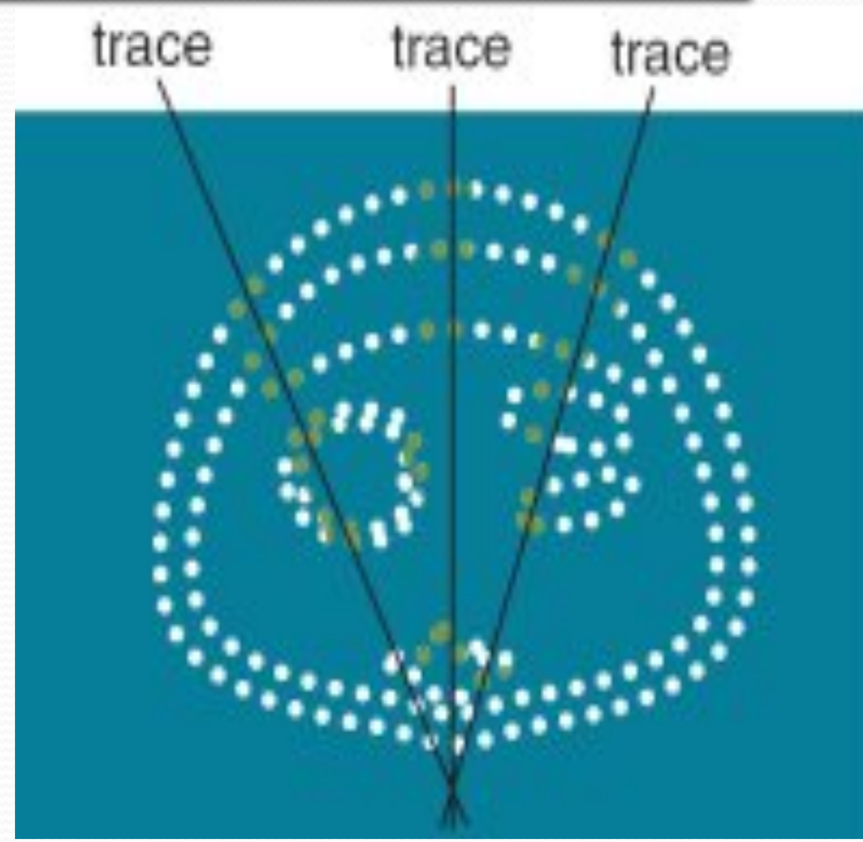
B-Scan(II)

- Each reflected pulse is shown as a bright dot to represent the position of reflecting surfaces

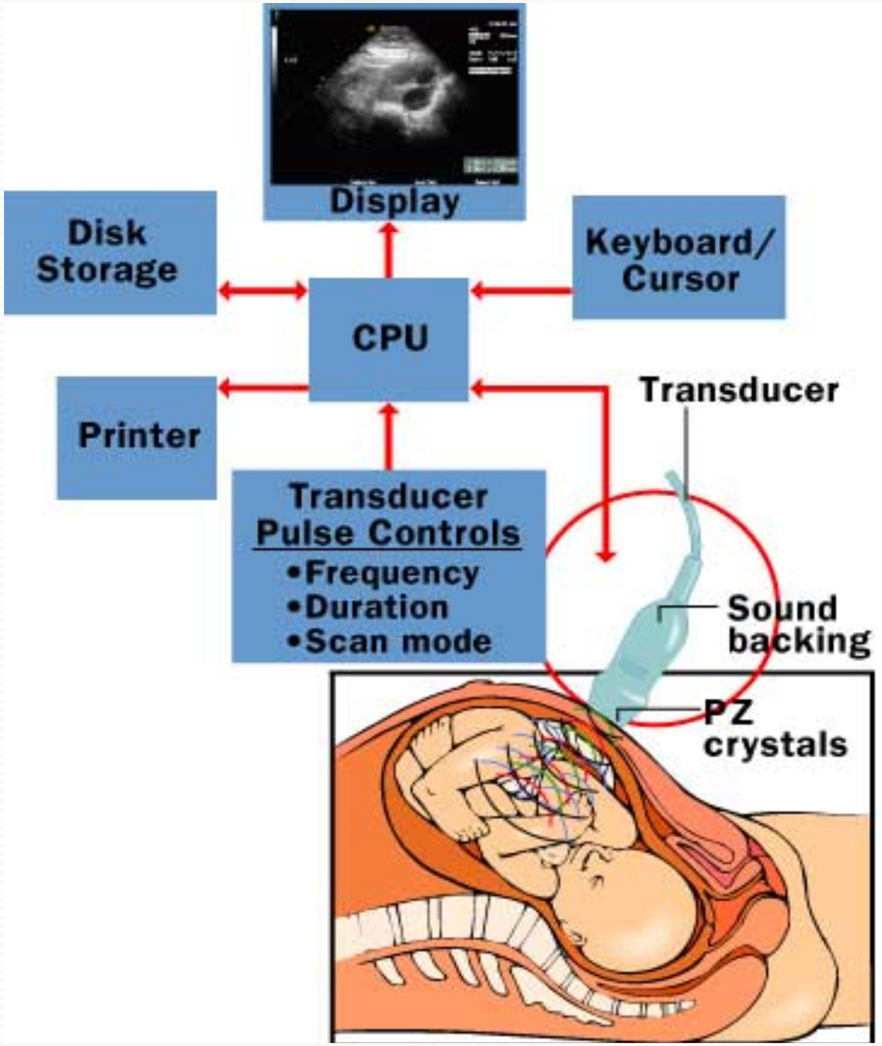
$\Rightarrow$

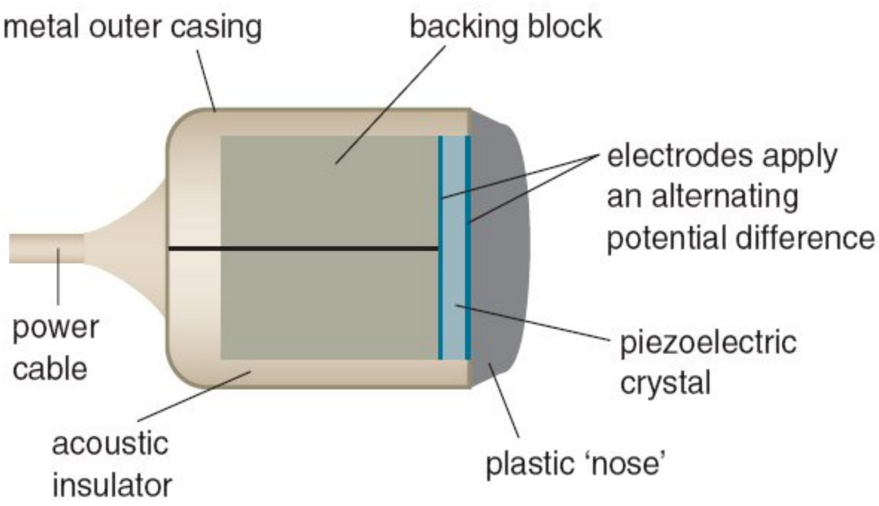
trace out the shape of the organ being examined

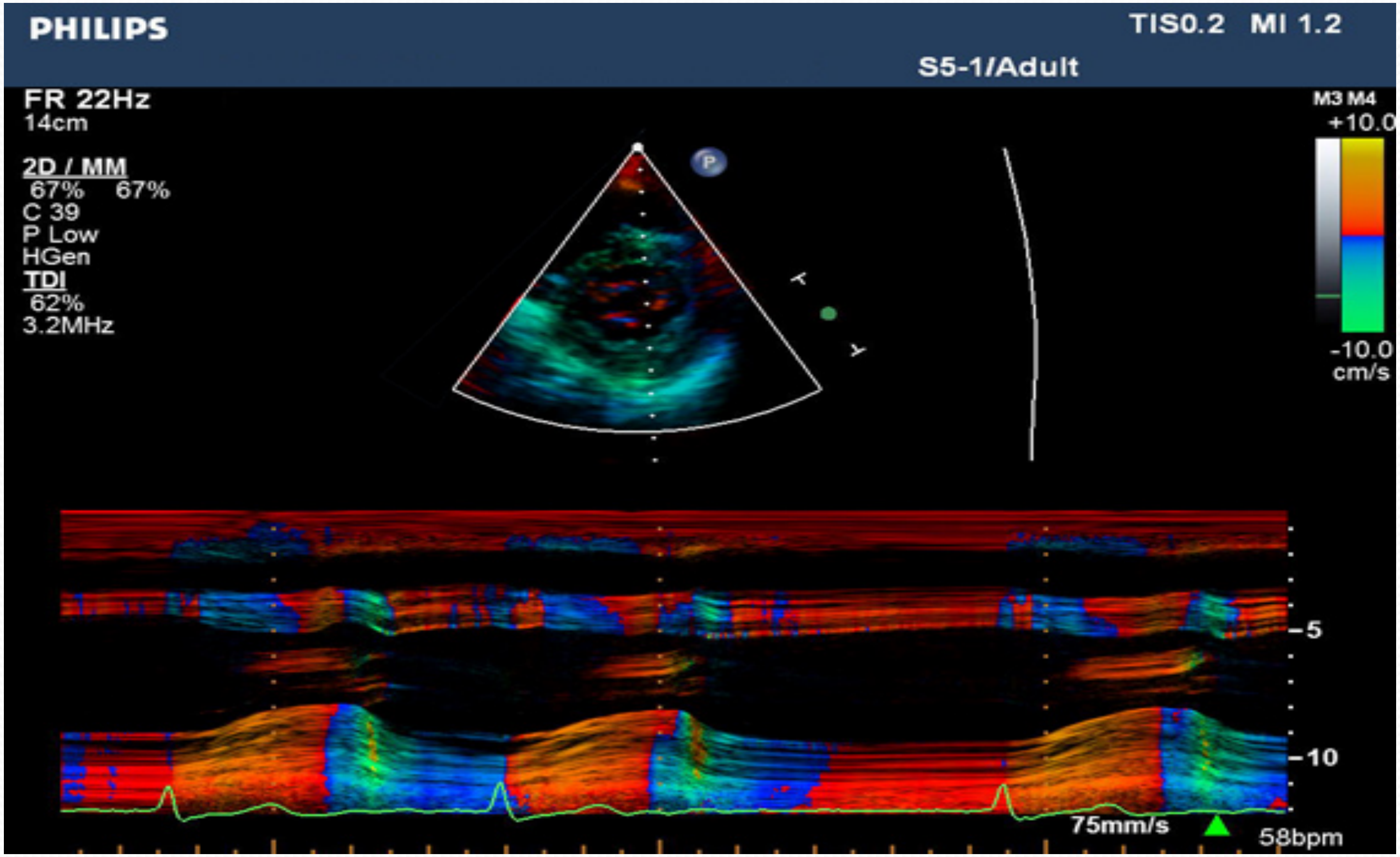




Schematic diagram of Ultrasound System






PHILIPS
TIS0.2 MI 1.2
S5-1/Adult
FR 22Hz
14cm
2D / MM
67% 67%
C 39
P Low
HGen
TDI
62%
3.2MHz
M3 M4
+10.0
-10.0
cm/s
5
10
75mm/s
58bpm

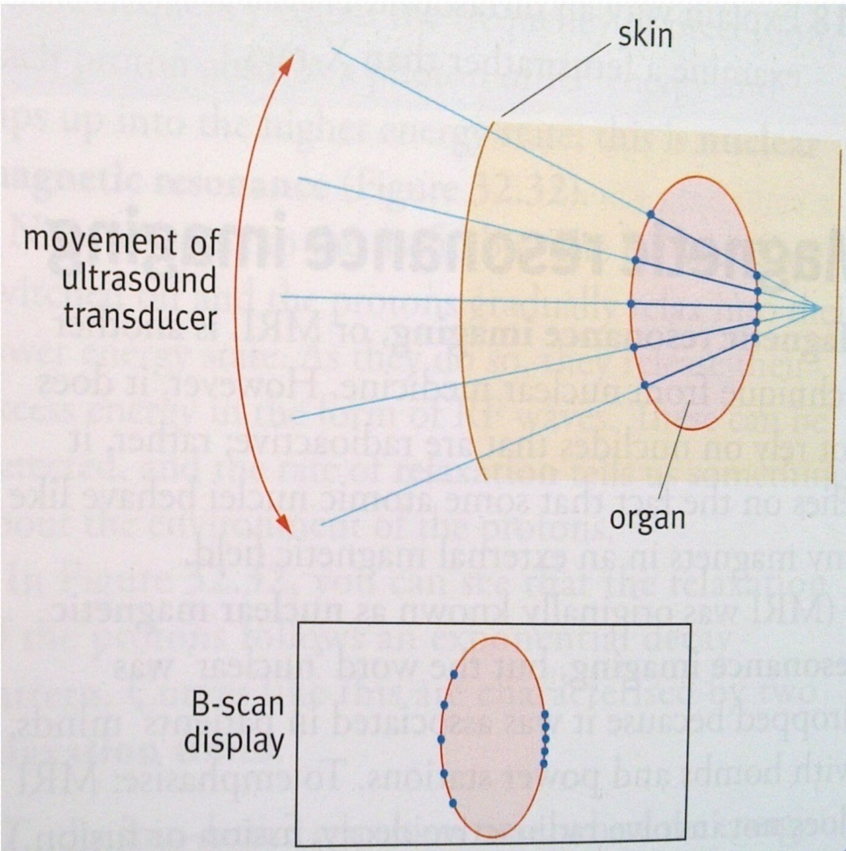

skin
movement of ultrasound transducer
organ
B-scan display


IMAGE NOT DIAGNOSTIC

Ultrasound: + points

- It is used to visualize **muscles, tendons, and many internal organs, their size, structure and any pathological** **lesions** with real time tomographic images. They are also used to visualize a fetus during routine and emergency **prenatal care**.

- The technology is relatively **inexpensive** and **portable**, especially when compared with modalities such as magnetic resonance imaging(MRI) and computed tomography (CT).

- It poses **no known risks** to the patient, it is generally described as a "safe test" because it does not use ionizing radiation, which imposes hazards (e.g. cancer production and chromosome breakage).

- However, it has two **potential physiological effects**: it enhances inflammatory response; and it can heat soft tissue.

Ultrasound : Limitation

- Ultrasound waves are reflected by air or gas; therefore ultrasound is **not an ideal imaging technique for the bowel**.
- Ultrasound waves **do not pass through air**; therefore an evaluation of the **stomach, small intestine and large intestine may be limited**. Intestinal gas may also prevent visualization of **deeper structures such as the pancreas and aorta**.
- Patients who are **obese are more difficult** to image because tissue attenuates (weakens) the sound waves as they pass deeper into the body.
- Ultrasound has **difficulty penetrating bone** and therefore can only see the outer surface of bony structures and not what lies within.