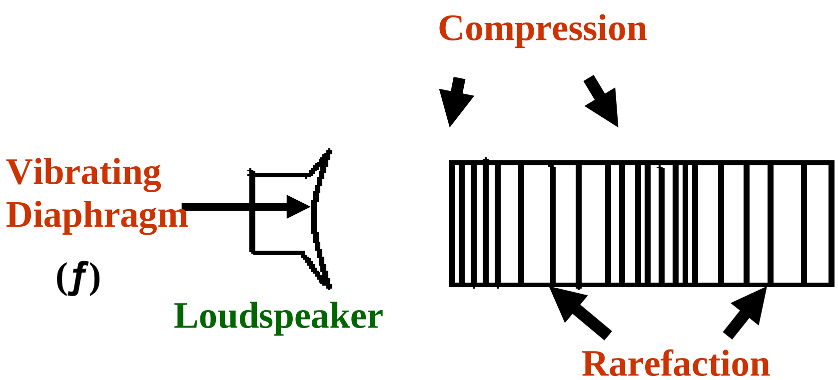
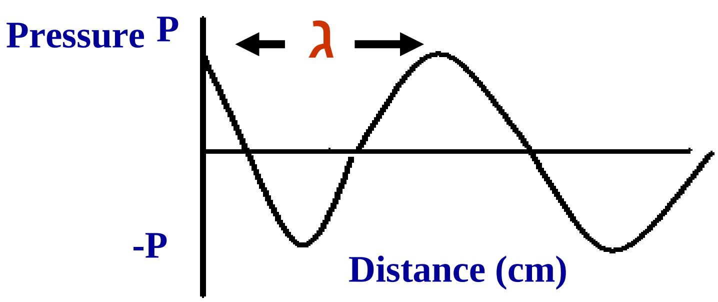
Physics of Ultrasound/ Part 1

1. Sound:

A sound wav is a mechanical disturbance in gas, liquid, or solid that travels outward from the source with some definite velocity. This disturbance makes the medium vibrates to cause a local pressure increase ***(Compression)*** and pressure decrease ***(Rarefaction)***. So, the sound is a mechanical longitudinal wave (wave in which the pressure changes occur in the same direction the wave travels) that propagates through the medium by compression and rarefaction.





The audible sound range is usually defined as 20 Hz to 20 KHz. ***Infrasound*** refers to sound frequencies below the normal hearing range. Or less than 20 Hz, it is produced by natural phenomena like earthquake waves and atmospheric pressure changes. The frequencies range above 20 KHz is called ***ultrasound*** which is used clinically in number of specialties and the use of ultrasonic equipment such as in ultrasonic imaging of the body.

The relation ship between the frequency of the sound wave (f), the wavelength (λ), and the velocity of the sound wave (ν) is:

$$(\nu = \lambda \times f)$$

Where:

V is the velocity of sound in the medium in (m/ sec). The velocity of the sound in air is 344 m/ sec

Ƒ is the frequency of vibration of the sound wave in (Hz)

λ is the wavelength in (m)

The ***intensity* (I)** of the sound wave is the energy passing through 1 m^2/ sec or watts per square meters, where I is measured in Bel or decibel (dB),1 Bel = 10 dB. For hearing tests, it is convenient to use a reference sound intensity to which other sound intensities can be compared, the reference sound intensity $I_\circ$ is $10^{-16} W/cm^2$. The most intense sound that the ear can tolerate without pain is 160dB, sound intensities above 160dB can cause eardrum rapture.

The ***Acoustic Impedance (Z)*** for the sound wave van be calculated from the equation:

$$(Z = \rho \times v)\ Kg/m^2.sec$$

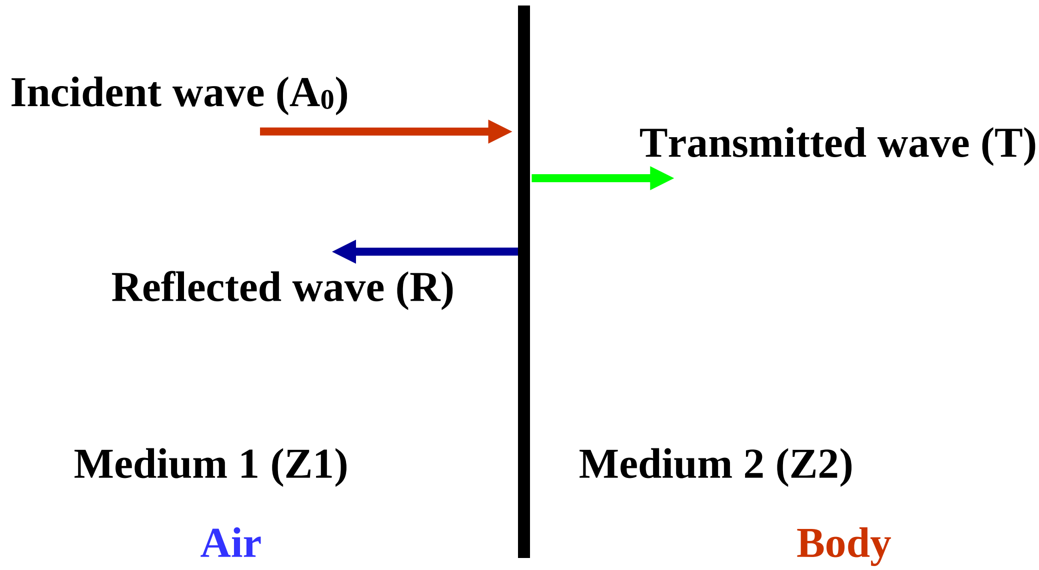
Where: P is the density of the medium where he sound wave transfer through it (Kg/m^3)

V is the velocity of sound wave in the that medium (m/ sec)

Substance	***P (Kg/m^3)***	***V (m/sec)***	***Z Kg/m^2.sec)***
Air	**1.29 x 103**	**3.31x 102**	**430**
Water	**1 x 103**	**14.8 x 102**	**1.48 x 106**
Brain	1.02 x 103	15.3 x 102	1.56 x 106
Muscle	1.04 x 103	15.8 x 102	1.64 x 106
Fat	0.92 x 103	14.5 x 102	1.33 x 106
bone	1.9 x 103	40.4 x 102	7.68 x 106

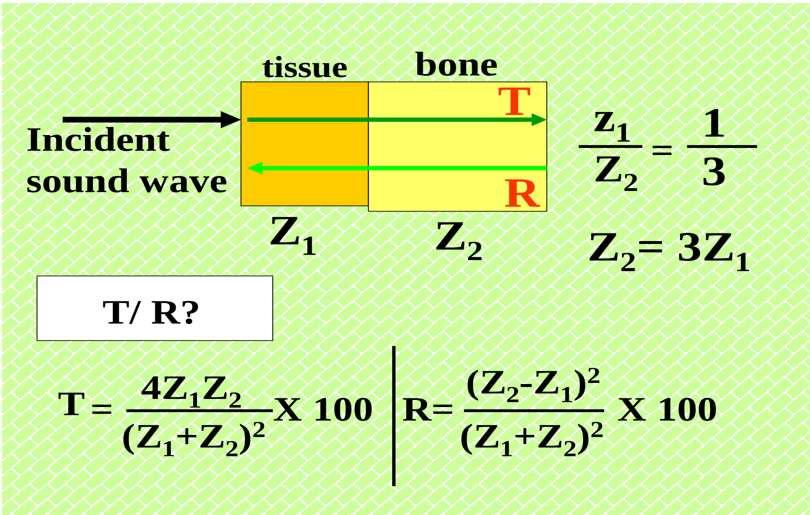
2. Sound/ Ultrasound Waves Reflection, Transmission and Absorption:

When a sound wave hits the body, part of the wave is reflected and part is transmitted into the body. The ratio of the reflected amplitude **(R)** to the incident amplitude **(A_0)** depends on the acoustic impedances of the two media **Z1** and **Z2.**



Example:

A beam of ultrasound incident on tissue bone system of acoustic impedance ratio 1:3. Calculate the ratio of the transmitted to the reflected beam.



3. Attenuation of Ultrasound Wave:

When a sound wave passes through tissue, there is some loss in the energy due to the frictional effects. The absorption of energy in the tissue causes a reduction in the amplitude of the sound wave ***(attenuation).***

The Ultrasound wave amplitude (A) at a depth (x) is related to the initial amplitude A_0 (X=0) according to the exponential equation:

$$[A = A_0 e^{-\alpha x}]$$

Since I is proportional to A^2

$$[\quad I = I_0 e^{-2\alpha x}]$$

α is the attenuation coefficient of the absorber at a particular frequency.
I is the intensity of Ultrasound wave

- A beam of ULS incident on a 3cm of muscular tissue, where 20% of the beam is absorbed. Calculate the amount of attenuation of this beam.

$$I = I_0 e^{-2\alpha x}$$

$$80 = 100 e^{-2\alpha 3}$$

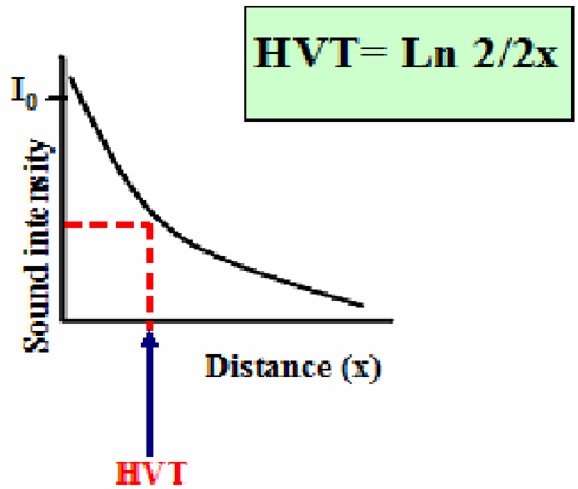
$$\text{Ln}0.8 = \ln e^{-2\alpha 3}$$

$$-0.22 = -6\alpha$$

$$\alpha = -0.22/6 = 0.036\ \text{cm-1}$$

4. Half Value Thickness (HVT):

It is the path length (tissue thickness) needed to reduce the beam intensity to 50% of the original intensity **($I = I_0/2$)**



5. Generation of ultrasound:

Ultrasound generators are ***transducers*** which convert the electrical energy to mechanical energy and visversa.

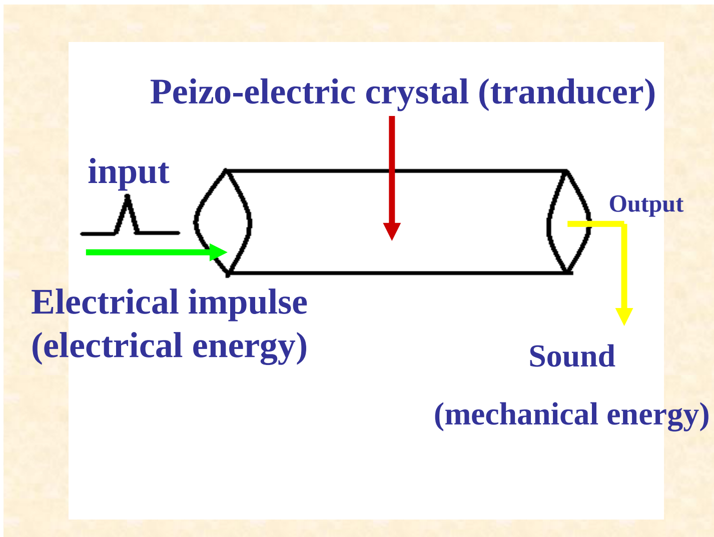
The medical ultrasound is generated by the peizo-electric effect in which many crystals can be cut so that an oscillating voltage across the crystal will produce a similar vibration of the crystal and generate sound waves. Piezo-electric effect:

There are certain materials that generate electric potential or voltage when mechanical strain is applied to them or conversely when the voltage is applied to them, they tend to change the dimensions along certain plane. This effect is called as the piezoelectric effect. This effect was discovered in the year 1880 by Pierre and Jacques Curie. Some of the materials that exhibit piezoelectric effect are quartz, Rochelle salt, polarized barium titanate, ammonium dihydrogen, ordinary sugar etc.

Characteristics of piezoelectric crystal:

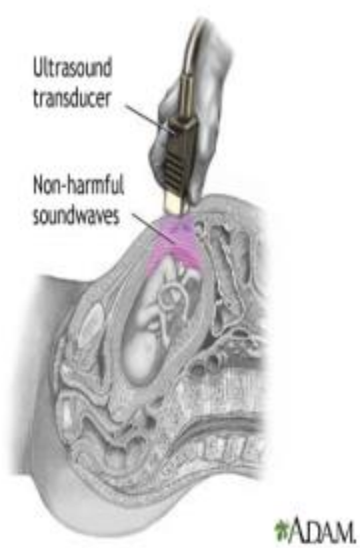
1- Electromechanical behavior
2- Vibrate at a frequency similar to its natural resonant frequency
3- It can change its dimensions

<u>Piezoelectric crystals types used for medical purposes:</u>
Some naturally occurring materials possess piezoelectric properties (e.g quartz)
Most of the medical ultrasound crystals are (man made), they are group of artificial materials which are known as (ferroelectrics) e.g (Barium titanate), (lead zirconate which is commonly known as PZT.



Each transducer has its own natural frequency of vibration ***(resonant frequency).*** The resonant frequency depends on:

1- the type of crystal.
2- the thickness of crystal.
The ***thinner*** the crystal the ***higher*** frequency at which it oscillate



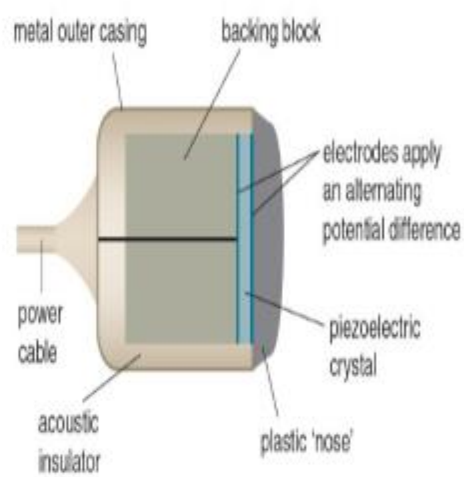


Fig 20-5 P328 (another ultrasound transducer fig.)