Dentistry College　　　　*Medical Physics*

Sound in Medicine

Dr.Muhannad Sami

The audible sound range is usually defined as 20Hz to 20.000Hz (20 kHz). However, relatively few people can hear over this entire range. The frequency range above 20 kHz is called ultrasound. Ultrasound is used clinically in a number of specialties, it often gives more information than an X-ray, and it is less hazardous for the fetus. Infrasound refers to sound frequencies below the normal hearing range, or less than 20Hz

General properties of sound

A sound wave is a mechanical disturbance in a gas, liquid, or solid that travels outward from the source with some definite velocity. We can use a loudspeaker vibrating back and forth in air at a frequency f to demonstrate the behavior of sound. The vibrations cause local increases and decreases in pressure relative to atmospheric pressure. These pressure increases, called compressions, and decreases, called rarefactions, spread outward as a longitudinal wave, that is, a wave in which the pressure changes occur in the same direction the wave travels.

The relationship between the frequency of vibration f of the sound wave, the wavelength λ, and the velocity v of the sound wave is ($v = \lambda$ f).

Energy is carried by the wave as potential and kinetic energy. The intensity I of a sound wave is the energy passing through $1m^2$/sec, or watts per square meter. For a plane wave I is given by: -

$$I = \frac{1}{2}\rho v A^2 (2\pi f)^2 = \frac{1}{2} Z (A\omega)^2$$

Where ρ is the density of the medium; v is the velocity of sound; f is the frequency; ω is the angular frequency, which equals $2\pi f$.

A is the maximum displacement amplitude of the atoms or molecules from the equilibrium position; and Z, which equals $(\rho \times v)$ is the acoustic impedance. The intensity can also be expresses as: -

$$I = \frac{P_o^2}{2Z}$$

Where P_o is the maximum change in pressure.

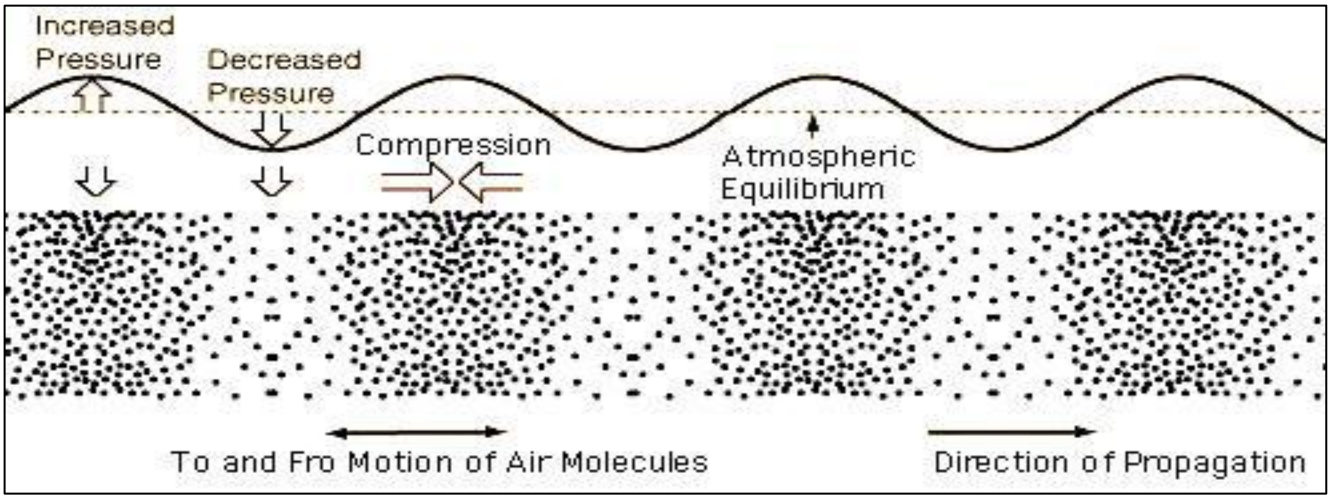


Figure 1 sound wave compression and rarefaction

Example1:- a. The maximum sound intensity that the ear can tolerate at 1000Hz is approximately $1 W/m^2$. What is the maximum displacement in air corresponding to this intensity? (ρ_{air}=$1.29 kg/m^3$), (v=3.31×10^2 m/sec){see table 12.1,Page255 Cameron}.

$$A = \frac{1}{2\pi f} \times \sqrt{\left(\frac{2I}{Z}\right)}$$

$$A = \frac{1}{2 \times 3.14 \times 1000} \times \sqrt{\frac{2 \times 1}{1.29 \times 3.31}}$$

$$A = 1.1 \times 10^{-5} m$$

b. The faintest sound intensity the ear can hear at 1000Hz is approximately$10^{-12}W/m^2$. What is *A* under these conditions?

$$\frac{A_b}{A_a}=(\frac{I_b}{I_a})^{1/2}$$

$$A_b=A_a(\frac{I_b}{I_a})^{1/2}=1.1x10^{-5}(\frac{10^{-12}}{10^0})^{1/2}=1.1x10^{-11}m$$

c. Calculate the sound pressures for cases a and b.

$$P_o=\sqrt{2ZI}$$

$$P_{oa}=[(2)x430x(1)]^{1/2}=29N/m^2$$

$$P_{ob}=[(2)x430x(10^{-12})]^{1/2}=2.9x10^{-5}N/m^2$$

A special unit, the bel, has been developed for comparing the intensities of two sound waves (I_2/I_1). This unit was named after Alexander Graham Bell, who invented the telephone . The intensity ratio in bels is equal to $\log_{10}(I_2/I_1)$. Thus of one sound is ten times more intense than another, $(I_2/I_1)=10$, since $\log_{10} 10 = 1$, the two sound intensities differ by 1 bel. Because the bel is a rather large unit, it is common to use the decibel (dB) in comparing two sound intensities (1bel = 10dB).

Sound intensity level (db) =10 log (I_2/I_1)

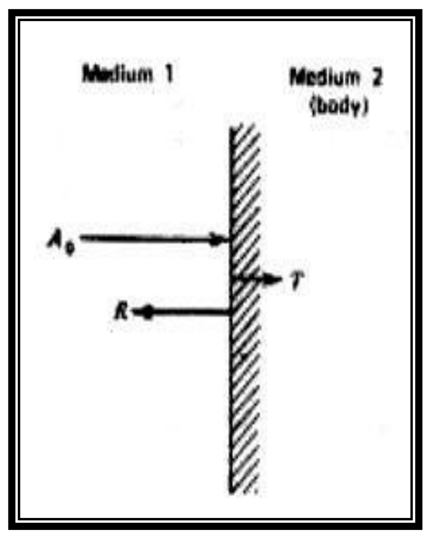
Since *I* is proportional to P^2, the pressure ratio between two sound levels can be expressed as 10 $\log_{10}(P_2^2/P_1^2)$, or 20 $\log_{10}(P_2/P_1)$. For hearing tests, it is convenient to use a reference sound intensity (or sound pressure) to which other sound intensities can be compared .The reference sound intensities I_o or(I_1) is 10^{-16} W/cm^2(**10^{-12}W/m^2**);$P_o=2\times10^{-4}$ dyne/cm^2.

Table 1: Approximate intensities of various sounds.

	Intensity (W/m^2)	Sound intensity level(db)
Sound that is barely perceptible	10^{-12}	0
Whisper	10^{-10}	20
Average dwelling	10^{-9}	30
Business office	10^{-7}	50
Speech at 1 m	10^{-6}	60
Busy street	10^{-5}	70
Subway or automobile	10^{-3}	90
Sound that produces pain	10^{0}	120
Jet aircraft	10^{1}	130
On rocket launch pad	10^{5}	170

Table 1 : gives the intensities of some typical sound in terms of this reference value. The most intense sound that the ear can tolerate without pain is about 120dB.

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 pressure amplitude R to the incident pressure amplitude A_o depends on the acoustic impedances of the two media, Z_1 and Z_2.



The relation is: -

$$\frac{R}{A_o} = \frac{Z_2 - Z_1}{Z_1 + Z_2}$$

For a sound wave in air hitting the body, Z_1 is the acoustic impedance of air and Z_2 is the acoustic impedance of tissue.

The ratio of the transmitted pressure amplitude T to the incident wave amplitude A_o is: -

$$\frac{T}{A_o} = \frac{2Z_2}{Z_1 + Z_2}$$

Example2:- Calculate the ratios of the pressure amplitudes of the reflected and transmitted sound waves from air to muscle (Z_1=430kg/m^2.sec), and (Z_2=1.64x10^{6}kg/m^2.sec).

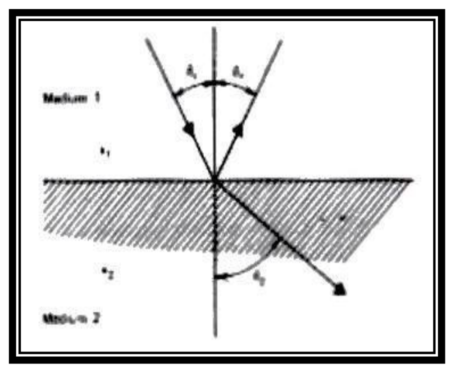
$$\frac{R}{A_o}=\frac{Z_2-Z_1}{Z_1+Z_2}=\frac{1.64x10^6-430}{1.64x10^6+430}=0.9995$$

$$\frac{T}{A_o}=\frac{2Z_2}{Z_1+Z_2}=\frac{2(1.64x10^6)}{1.64x10^6+430}\approx 1.9995$$

Choosing materials with similar acoustic impedances is called impedance matching. Getting sound energy into the body requires impedance matching. The geometric laws involving the reflection and refraction (bending) are the same as for light. This means that θincident =θ reflected, or (θi = θr).

The angle of the refracted sound wave θ_2 is determined by the velocities of sound in the two media v_1 and v_2 from the equation: -

$$\frac{\sin\theta_i}{\upsilon_1}=\frac{\sin\theta_2}{\upsilon_2}$$



When a sound wave passes through tissue, there is some loss of energy due to frictional effects. The absorption of energy in the tissue causes a reduction in the amplitude of the sound wave. The amplitude *A* at a depth x cm in a medium is related to the initial amplitude A_o (x=0) by the exponential equation ($A=A_oe^{-\alpha x}$) where α, in cm^{-1}, is the absorption coefficient for the medium at a particular frequency.

Since the intensity is proportional to the square of the amplitude, its dependence with depth is ($I=I_oe^{-\alpha x}$) where I_o is the incident intensity at x=0 and *I* is the intensity at a depth x in the absorber.

Ultrasound pictures of the body

Human ears respond to sound in the frequency range of about 20-20000 Hz, although many animals can produce and hear sounds of considerably higher frequencies. For example, bats emit blips of ultrasonic frequencies (30 to 100 kHz) and navigate by listening to the echoes. It was discovered during World War II that man can use ultrasound in much the same way bats can, The navy developed sonar (*SO*und *NA*vigation and *R*anging), a method of locating under water objects, such as submarines, with ultrasound echoes. After World War II medical engineers developed techniques for using ultrasound in diagnosis.

Basically, an ultrasound source sends a beam of pulses of 1 to 5 MHz sound into the body. The time required for the sound pulses to be reflected gives information on the distance to the various structures or organs in the path of the ultrasound beam.

While there are several methods of generating ultrasound, the most important for medical applications involves the piezoelectric effect. This effect was discovered by Jacques and Pierre Curie in about 1880.

A device that converts electrical energy to mechanical energy or vice versa is called a transducer. Ultrasound generators are often simply referred to as transducers. Each transducer has a natural resonant frequency of vibration. The thinner crystal, the higher the frequency at which it will oscillate. Pulses of ultrasound are transmitted into the body by placing the vibrating crystal in close contact with the skin, using water or a jelly paste to eliminate the air. This gives a good coupling at the skin and greatly increases the transmission of the ultrasound into the body and of the echoes back to the detector. The same transducer that produced the pulse serves as the detector. The weak signals are then amplified and displayed on an oscilloscope. Many of the applications of ultrasound in medicine are based on the principles of sonar. In sonar a sound wave pulse is sent out and is reflected from an object; from the time required to receive the echo and the known velocity of sound in water, the distance to the object can be determined.

To obtain diagnostic information about the depth of structures in the body, we send pulses of ultrasound into the body and measure the time required to receive the reflected sound (echoes) from the various surfaces in it. This procedure is called the A Scan method of ultrasound diagnosis.

It must be remembered that the basis for the use of ultrasound in medicine is the partial reflection of sound at the surface between two media that have different acoustical properties. The amount of the reflection depends primarily upon the difference in the acoustical impedances of the two materials and the orientation of the surface with respect to the beam. In many diagnostic uses of ultrasound the echoes are very small signals due to weak reflection and the absorption of the sound by tissue.

Applications of A Scans

1- Applications of A Scans in echoencephalography, has been used in the detection of the brain tumors. Pulses of ultrasound are sent into a thin region of the skull slightly above the ear and echoes from the different structures within the head are displayed on an oscilloscope.

2-Applications of A Scans in ophthalmology can be divided into two areas:

- Obtaining information for use in the diagnosis of eye diseases;
- Biometry, or measurements of the distances in the eye.

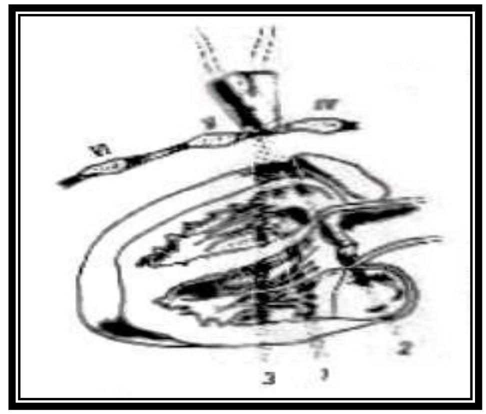
For many clinical purposes A Scans have been largely replaced by B Scans. The B Scan method is used to obtain two-dimensional views of parts of the body. The principles are the same as for the A Scan except that the transducer is moved. As a result each echo produces a dot on the oscilloscope at a position corresponding to the location of the reflecting surface.

B Scans provide information about the internal structure of the body. They have been used in diagnostic studies of the eyes, liver, breast, heart, and fetus. They can detect pregnancy as early as the fifth week and can provide information about uterine anomalies. Information on the size, location, and change with time of a fetus is extremely useful in both normal deliveries and cases such as abnormal bleeding and threatened abortion. In many cases B Scans can provide more information than X-ray, and they present less risk.

Ultrasound to measure motion

Two methods are used to obtain information about motion in the body with ultrasound; the M (motion) Scan, which is used to study motion such as that of the heart and the heart valves, and the Doppler technique, which is used to measure blood flow. The M Scan combines certain features of the A Scan and the B Scan. The transducer is held stationary as in the A Scan and the echoes appears as dots as in the B Scan.

M Scans are used to obtain diagnostic information about the heart. The places where the heart can be probed are quite limited because of poor ultrasound transmission through lung tissue and bone.



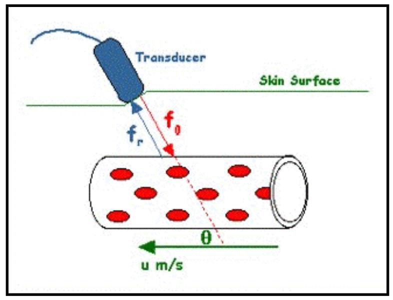
The usual methods is to put the transducer on the patient's left side, aim it between the ribs over the heart, and tip it at different angles to explore various regions of the heart. By moving the probe it is possible to obtain information about the behavior of a particular valve or section of the heart.

Since the early studies on sound in the 1800s, physicists have realized that a source of sound of frequency f_0 has a higher pitch when it is moving toward a listener and a lower pitch when it is moving away from him. It also has a higher pitch when the listener is moving toward the source than when he is moving away from it. The frequency change is called the Doppler Shift.

The Doppler Effect can be used to measure the speed of moving objects or fluids within the body, such as the blood. When a continuous ultrasound beam is "received" by some red blood cells in an artery moving away from the source, the blood "hears" a slightly lower frequency than the original frequency f_0. The blood sends back scattered echoes of the sound it "hears" but since it is now a source of sound moving away from the detector, there is another shift to a still lower frequency. The detector receives a back-scattered signal that has undergone a double Doppler Shift. When the blood is moving at an angle θ from the direction of the sound waves, the frequency change f_r is: -

$$f_r = \frac{2 f_o V}{\upsilon} \cos\theta$$

Where f_0 is the frequency of the initial ultrasonic wave, V is the velocity of the blood, v is the velocity of sound, and θ is the angle between V and v.



The Doppler Effect is also used to detect motion of the fetal heart, umbilical cord, and placenta in order to establish fetal life during the 12 to 20 week period of gestation when radiological and clinical signs are a continuous sound wave of frequency f_0 is incident upon the fetal heart, the reflected sound unreliable. When is shifted to frequencies slightly higher than f_0 when the fetal heart is moving toward the source of sound and slightly lower than f_0 when the fetal heart is moving away from it. Variations in the frequency give the fetal heart rate.

Physiological effects of ultrasound in therapy

Various physical and chemical effects occur when ultrasonic waves pass through the body, and they can cause physiological effects. The magnitude of the physiological effects depends on the frequency and amplitude of the sound.

The primary physical effects produced by ultrasound are temperature increase and pressure variations. The primary effect used for therapy is the temperature rise due to the absorption of acoustic energy in the tissue. Ultrasound diathermy complements deep heating electromagnetic diathermy. The ultrasound is applied with a piezoelectric crystal transducer with a radiating surface of approximately $10 cm^2$. A gel or mineral oil is used between the transducer and the skin for impedance matching. The probe should be calibrated and tuned in water before the treatment to determine the average intensity and total power output.

Many times the applicator is moved slowly in a back-and-forth stroking motion to avoid forming "hot spots" in the tissue. Ultrasound deposits its energy in the deeper muscles and tissues of the body while causing little temperature rise in the soft surface tissue layers.

Ultrasound diathermy is helpful in the treatment of joint disease and joint stiffness. It has also been used on joints that have calcium deposits.

Ultrasound waves differ completely from electromagnetic waves; they interact with tissue primarily by microscopic motion of the tissue particles.

As a sound wave moves through tissue, the regions of compression and rarefaction cause pressure differences in adjacent regions of tissue. Stretching occurs in these regions; if the stretching exceeds the elastic limit of the tissue, tearing results.

Intense ultrasound waves can change water into H_2 and H_2O_2 and rapture DNA molecules.

Negative pressure in the tissue during rarefaction can cause dissolved gas to come out of solution and form bubbles. This forming of bubbles, called cavitations, can break molecular bonds between the gas and tissue. The collapse of the bubbles releases energy that can also break bonds. Free radicals produced during the breaking of bonds can lead to oxidation reactions.

Some studies with ultrasound have shown that cancer cell destruction does occur in some regions of treated tumors.

Ultrasound was at one time used successfully on patients suffering from Parkinson's disease.

Meniere's disease, a condition involving dizziness and hearing loss, has been treated with intense ultrasound with nearly 95% success. The ultrasound destroys tissues near the middle ear.

The production of speech (Phonation)

Normal speech sounds are produced by modulating an outward flow of air. For most sounds the lungs furnish the stream of air, which flows through the vocal folds (cords), sometimes called the glottis, and several vocal cavities and exits from the body through the mouth and to a slight degree through the nostrils. The speech sounds produced in this way are called voiced sounds. Some sounds are produced in the oral portion of the vocal tract without the use of the vocal folds-these are called unvoiced sounds