Karbala University-College of veterinary medicine

Medical Physics-Lecture (7)

Sound in Medicine

Infrasound refers to sound frequencies below the normal hearing range, or less than **20Hz**.

The **audible sound** range is usually defined as **20Hz** to **20.000Hz** (**20kHz**). However, relatively few people can hear over this entire range.

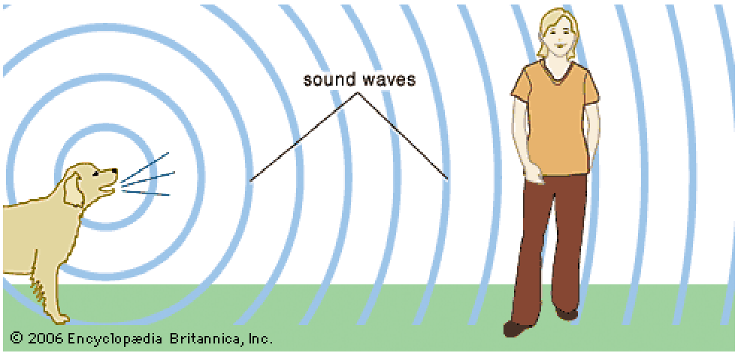
The frequency range above **20kHz** is called **ultrasound**. **Ultrasound** is used clinically in a number of specialties. It often gives more information than an **X-ray**, and it is less hazardous for the fetus.

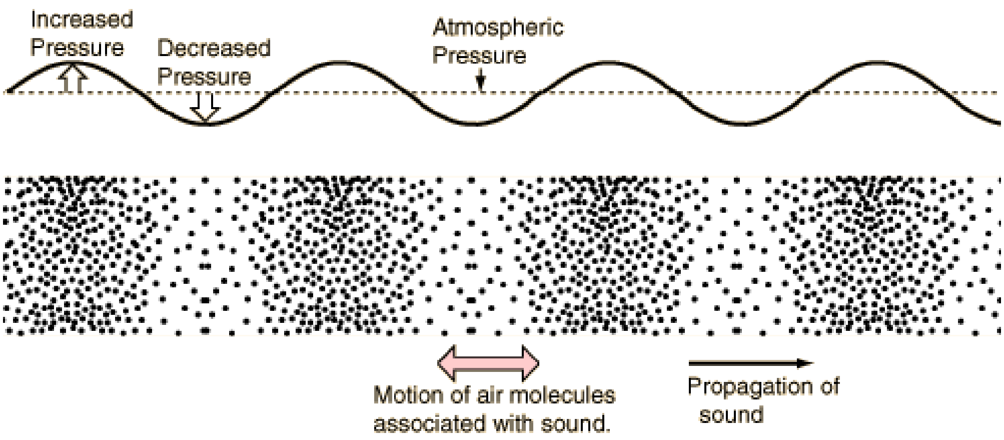
General properties of sound

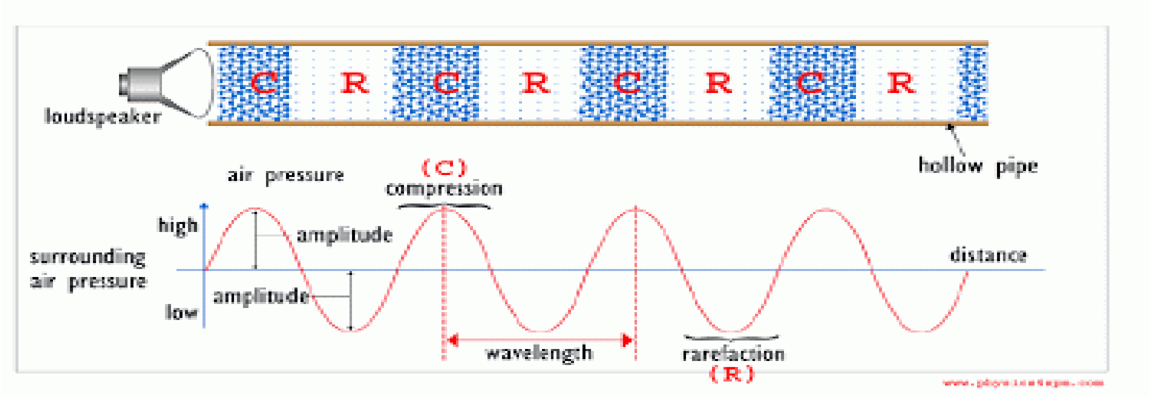
The vibrations cause local **increases** and **decreases** in pressure relative to atmospheric pressure. These pressure increases, called **compressions**, and decreases, called **rarefactions**, spread outward as a **longitudinal wave**, that is, a wave in which the pressure changes occur in the same 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 ($v=\lambda f$).

For example, for a sound wave with a frequency of 1000 Hz , v=344 m/sec in air at 20 ^{0}C and λ=0.344 m.







There is a resistant to passage of a sound wave through a medium which is analogous to electrical resistance. This is called **acoustic impedance** Z, which is given by:

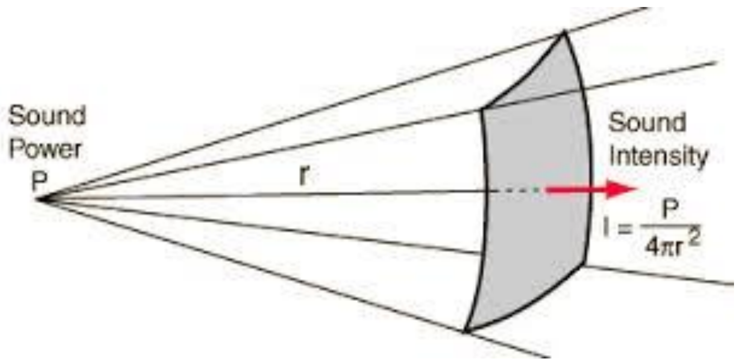
$$Z=\rho c$$

ρ : density of the medium

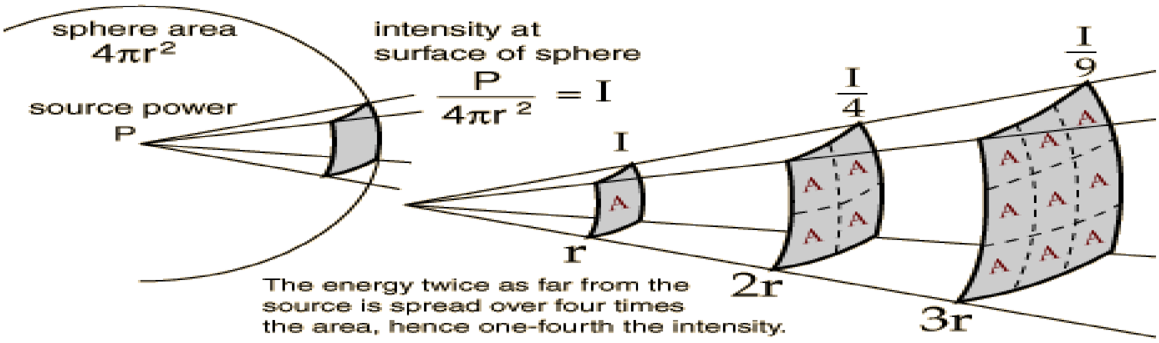
c: velocity o f sound at that medium

This is an important quantity in determining how much sound is transmitted from one medium to another. If the impedance of the two media are very different, for example a gas and a liquid, then much of the sound will be reflected, not transmitted at the interface. The media are said to be acoustically mismatched.

Sound intensity



Variation of intensity with distance: the inverse square law:



As a wave passes through a medium it will gradually lose intensity by **attenuation**. This is the result of a number of processes of interaction between the wave and the medium including absorption, diffraction scattering and others.

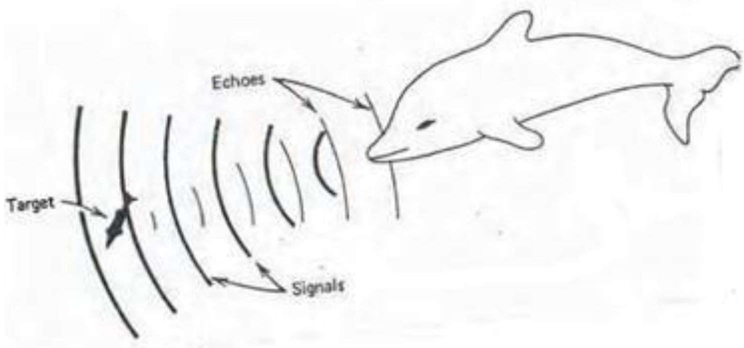
As with any wave transmission, the intensity falls by a constant fraction for each unit of distance travelled, which leads to an exponential fall of intensity with distance. Intensity at a distance x from the original intensity I_o is given by

$$I_x=I_o e^{-\mu x}$$

Where **μ** is called the attenuation coefficient.

Ultrasound pictures of the body

The **SONAR** (**SO**und **NA**vigation and **R**anging) a method of location underwater objects, such as submarines, with ultrasound echoes. After World War II medical engineers developed techniques for using ultrasound in diagnosis. In this section we discuss the use of ultrasound to produce pictures for medical diagnosis. Basically ,an ultrasound source sends a beam of pulses of 1 to 5MHz sound in the body. The time required for the sound pulses to be reflected gives information on the distances to the various structures or organs in the path of the ultrasound beam(Figure 3)



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.

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.

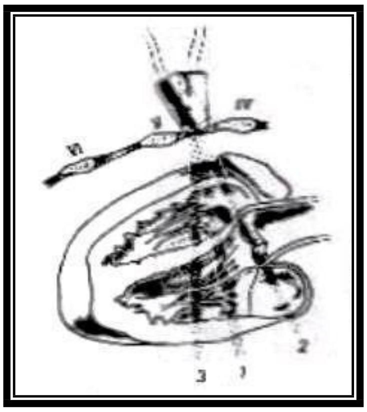
Ultrasound to measure motion

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 (figure7).



Since the early studies on sound in the 1800s, physicists have realized that a source of sound of frequency f_o 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_o. 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**

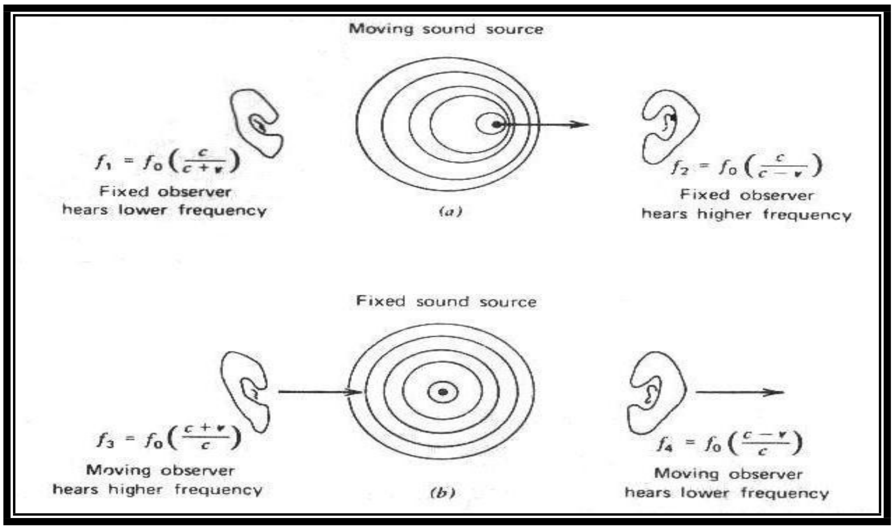


Figure (8): The Doppler Effect, (***a***) The listener hears a higher frequency from a sound source moving toward him and a lower frequency when it is moving away from him. (***b***) A listener hears a higher frequency when he is moving towards a sound source than when he is moving away from it. Here ***c*** is the velocity of sound in air, ***v*** is the velocity of the source in (***a***) and the listener in (***b***), and f_o is the frequency in the absence of motion

When the blood is moving at an angle ϑ from the direction of the sound waves, the frequency change f_d is:-

$$f_d = \frac{2f_\circ V\cos\theta}{v}$$

Where f_o 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***.

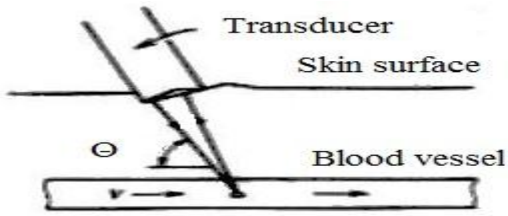


Figure (9) schematic arrangement for using the Doppler effect to measure the velocity of blood in a blood vessel.

Reflection :

This occurs at a boundary because of a difference in the characteristic **acoustic impedance Z** , of each substance.

(remember Z = ρc : ρ is the density of medium , c is the velocity of sound in that medium)

It can be shown that the ratio of the reflected intensity I_r to the incidental intensity I_i is :

$$I_r / I_i = (Z_2 - Z_1)^2 / (Z_2 + Z_1)^2$$

Clearly there will be no reflection if the impedance of the two media is the same $Z_1 = Z_2$.

Example

Calculate the percentage of reflected intensity of ultrasound waves at the interface between air and soft tissue (i.e ultrasound waves are passing from the air to the soft tissue).

Consider the acoustic impedance of air is 430 kg $m^{-2}S^{-1}$ and that of soft tissue is 1.64 * 10^6 kg $m^{-2}S^{-1}$.

$$I_r/ I_i = (Z_2-Z_1)^2/(Z_2+Z_1)^2$$

Z_1 is of air & Z_2 is of soft tissue

$$I_r/ I_i = (1.64*10^6 - 430)^2/ (1.64*10^6 + 430)^2$$

$$= 0.9990$$

resonance

resonance is the tendency of a system to oscillate with greater amplitude at some frequencies than at others. Frequencies at which the response amplitude is a relative maximum are known as the system's **resonant frequencies.**

The stethoscope

The stethoscope was invented in France in 1816 by René Laennec .

1- One of the original stethoscopes belonging to Rene Laennec made of wood and brass

Laennec (1781-1826) with stethoscope

2- **Modern stethoscope**

The main parts of a modern stethoscope are the bell, which is either open or closed by a thin diaphragm, the tubing and the earpieces

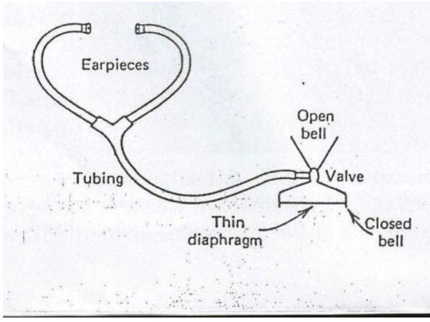


Figure 12.6. stethoscope.

Ultrasound

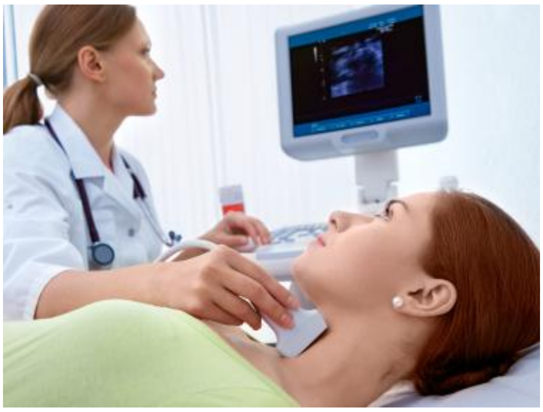
The limits of human hearing are between 20-20000 Hz, though animals make use of sound at considerably higher frequencies. Bats and dolphins, for example, emit pulses of sound in the 30-100 KHz range and navigate by listening to the echoes.

Ultrasound (US) has frequencies above 20 KHz.

Generation and detection of Ultrasound

The ultrasonic transducer is the device which can both generate and detect ultrasound vibrations.

Ultrasonic transducers used in medicine convert electrical energy into ultrasound, and the opposite, by means of the piezoelectric effect.



Sonographer handling ultrasound probe to examine the neck of a young lady

To avoid the presence of air between the skin the transducer and Because the gel has acoustic impedance ≈ that of soft tissues so that small percent of ultrasound waves are reflected at the interface

Exercise

The time delay for an echo from ultrasound in soft tissue was 0.133 milliseconds. At what depth was it reflected ?

note that the speed of sound in soft tissues is about 1500 ms^{-1} .

Answer

v = d/t

d = v * t = 0.133 millisecond * 10^{-3} * 1500 ms^{-1}

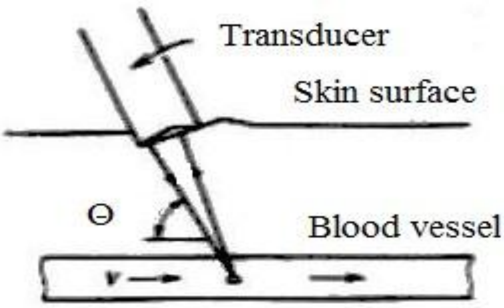
= 0.1995 m = 19.95 cm ≈ 20 cm

But the pulse travels both ways

So the depth = 20/2 = 10 cm

The Medical Applications of Sound

1. The intensity of ultrasound used for **medical diagnostic(التشخيص الطبي)** is kept low to avoid tissue damage. Intensities of about **10^{-2}W/m^2** are used and seem to cause no ill effects.
2. Ultrasound of considerably higher intensity is used for **therapeutic purposes**. Ultrasound diathermy is deep heating using**(التسخين العميق)** ultrasound of intensities **1- 10W/m**^{2}.
3. Ultrasonic sound waves sent into the body are **Doppler shifted** by any motion in the objects that reflect them. It is possible, ***for example***, to measure blood velocity(سرعة الدم) by observing the **Doppler shift** of ultrasound reflected from the blood cells. More commonly, the Doppler shift of ultrasound is used to monitor the fatal heart motion.
4. The ultrasound used for sterilization(تستخدم الموجات الفوق الصوتية في التعقيم) **because** it kills the virus and bacteria.
5. It is also used as massage tool for muscles(تدليك العضلات): cure the cancer(علاج السرطان), destruction the kidney stone(وتدمير الحجر في الكلة).
6. Many devices use ultra-sonic sound, like **toothbrushes(**فرشاة الاسنان الفائقة الصوتية**)** Sonic denture cleaner (نظافة الاسنان)or sonic cleaning device eliminates lime scale deposits.
7. Ultra-Max Cube: multiple of uses such as cleaning brushes, dentures(تركيب طقم الاسنان), burs, diamonds, etc.

schematic arrangement for using the Doppler effect to measure the velocity of blood in a blood vessel.