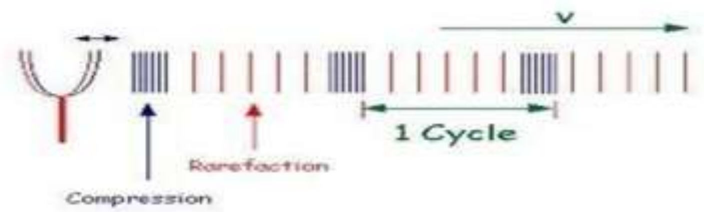
Lecture Six Sound In Medicine

The audible sound range defined as (20Hz $\longrightarrow$ 20KHz) older people lose the ability to hear frequencies above 10 KHz. The frequencies range above 20 K Hz called ultrasound.

GENERANL PROPERTIES OF SOUND

- Sound wave is mechanical waves,
- The vibrations cause local increases and decreases in pressure relative to atmospheric pressure.
- The pressure increases called compressions, and decreases called rarefaction.
- Compression and rarefaction can be described by density changes and by displacement of the atoms and molecules from their equilibrium position.



A sound wave is a mechanical disturbance in a gas, liquid, or solid that 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** , the wavelength **λ** , and velocity **V** of the sound wave is

V = λ f

Energy is carried by the wave as potential and kinetic energy. The intensity (**I**) of a sound wave energy passing through ($\mathbf{1m^2/s}$). Or watts per square meter for plane wave **(I)** is given by:

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

Where ρ: is the density of the medium

V: is the velocity of sound

f: is the frequency

W: is the angular frequency which equals **2π f**

A: is the maximum displacement amplitude of atoms from equilibrium position

Z : equals **ρ V**, is the acoustic impedance.

The intensity can also be expressed as

$$I = P_o^2 / 2Z$$

Where $\mathbf{P_o}$ is the maximum change in pressure.

Example.1

a- The maximum sound intensity that the ear can tolerate at (1000 Hz**)** is approximately (**1** W/m^2). What is the maximum displacement in air corresponding to this intensity?

Solution :

$$A = \frac{1}{2\ \pi f})\ \left(\frac{2I}{z}\right)^{\frac{1}{2}} = \frac{1}{6.28\,x10^{\,3}}\,(\frac{2\ x\ I}{4.3\ x\ 100})^{\ \frac{1}{2}} = 1.1\ x\ 10^{-5}m$$

b- The faintest sound intensity the ear can hear at 1000 Hz is approximately(10 exp -12 w/m2) . what is (A) under these conditions?

We can use ratios between case (**a**) and this case

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

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

This displacement is smaller than the diameter of the hydrogen atom

C- Calculate the sound pressure for cases (**a**) and (**b**)

$$P_o = \sqrt[2]{2\, I\, Z} = \sqrt[2]{2 \,x\, 4.3 \,x\, 100 \,x\, I}$$

$$= 29\ N/m^2 = 0.0003\ \text{Atmosphere}$$

$P_{ob} = 2.9 \times 10^{-3}$ N/m^2

For comparison , atmospheric pressure is about $\mathbf{10^5}$ N/m^2

For comparing the intensities of two waves (I_2/I_1) . This was named after Alexander bell . The intensity ratio in bells equal to $\mathbf{\log_{10} (I_2/I_1)}$, and **(1 bel= 10 dB)** it is common to use the describe comparing two sound intensities. Since **I** is proportional to $\mathbf{P^2}$, the **pressure ratio** between two sound levels can be expressed as

$$10 \log_{10} (P_2^2/P_1^2),\ \text{or}\ 20 \log_{10} (P_2/P_1)$$

This can be used to compare any two sound pressures in the same medium. For two sounds with pressures that differ by factor (2) we get

$$20 \log_{10} (P_2/P_1) = 20 \log_{10} 2 = 20(0.301) = 6\ dB$$

For hearing tests, it is convention to use a reference sound intensity or sound pressure to which other sound intensities can be compared. The reference sound intensity

$$I_o \text{ is } 10^{-16}\ W/cm^2, \text{ or } 10^{-12}\ W/m^2$$

$$P_o \doteqdot 2x\ 10^{-4}\ dyne/cm^2$$

If a sound intensity is given in decibels with no reference to any other sound intensity , you can assume that **I_o** is the reference intensity.

H.w

The sound intensity levels of (10^4 W/m^2) can cause damage of the eardrum diaphragm. What is the displacement of the diaphragm at such intensity adopting an average frequency (1000Hz) ? Where the acoustic impedance for tissue equal ($1.64x10^4$ Kg/m^2s) ?.

When a sound wave hits the body, part of the wave is reflected and part is transmitted into the body.

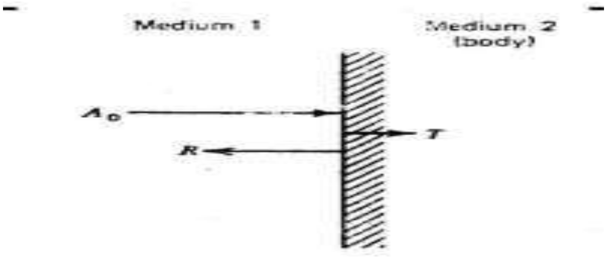


Figure A sound wave of amplitude A_o incident upon the body.

R : is the reflected pressure amplitude .

Ao :is the incident pressure amplitude .

The ratio of **(R/Ao)** depends on acoustic impedance of the two media ,

($\mathbf{Z_1}$) and ($\mathbf{Z_2}$) **.** The relationship is

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

For a sound wave in air hitting the body, $\mathbf{Z_1}$ is the acoustic impedance of air and $\mathbf{Z_2}$ is the a acoustic impedance of tissue. If $\mathbf{Z_1 = Z_2}$ There is no reflected wave and transmission to the second medium is complete

If $\mathbf{Z_2 < Z_1}$ The sign change indicates a phase change of reflected wave. The ratio of the transmitted pressure amplitude **T** to the incident wave amplitude **Ao** is

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

It is obvious that whenever acoustic impedances differ greatly there is almost complete reflection of sound intensity this is the reason heart sounds are poorly transmitted into the air adjacent to the chest.

Example .2

Calculate the ratios of the pressure amplitudes and intensities of the reflected and transmitted sound waves from air to muscle.

$$R/A_o = \frac{1.64 \times 10^6 - 430}{1.64 \times 10^6 + 430}$$

$$= 0.9995$$

$$\frac{T}{A_o} = \frac{2(1.64 \times 10^6)}{1.64 \times 10^6 + 430}$$

$$\simeq 1.9995$$

Also we obtain the ratios of the reflected and transmitted intensities

$$(R^2/2Z_1) / (A_o^2/2Z_1) = (R/A_0)^2 = (0.9995)^2 = 0.9990$$

$$(T^2/2Z_2) / (A_o^2/2Z_1) = Z_1/Z_2(T/A_o)^2 = 0.001$$

When the acoustic impedances of the two media are **similar** almost all of the sound is transmitted into the second medium, choosing materials with similar acoustic impedance is **called** impedance matching. Getting sound energy into the body requires impedance matching.

Example.3

Calculate the amplitudes and intensities of the reflected and transmitted sound waves from water to muscle using the values from table (p.255)

$$\frac{R}{Ao} = \frac{(1.64-1.48)x10^6}{(1.64+1.48)x10^6} = 0.0513$$

$$\frac{T}{Ao} = \frac{2(1.64)x10^6}{(1.64+1.48)x10^6} = 1.0513$$

The ratio of the reflected and transmitted intensities are now

$$\left(\frac{R}{Ao}\right)^2 = (0.05013)^2 = 0.0026$$

$$\frac{Z1}{Z2}\left(\frac{T}{Ao}^2\right) = \frac{1.48\,x10^{\,6}}{1.64\,x10^{\,6}}(1.0513)^{\,2} = 0.9974$$

When a wave hits an angle (Θi) to a boundary between two media

$$\frac{sin\Theta_1}{V_1} = \frac{sin\Theta_2}{V_2}$$

V_1 and V_2 are the velocities of sound in two media, Θ_1 is the angle of the incident wave, Θ_2 is the angle of the refracted sound wave. Because sound can be refracted, acoustic lenses can be constructed to focus sound waves. When sound wave passes through tissue, there is some loss of energy due to frictional effects. The absorption of energy in the tissue cause a reduction in the amplitude of sound wave. The amplitude **(A**) at a depth (**X)** cm in medium is related to initial amplitude A_o **(x=0)** by the exponential equation :

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

Where α , is the absorption coefficient for the medium. Since the intensity is proportional to the square of the amplitude, its dependence with depth is :

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

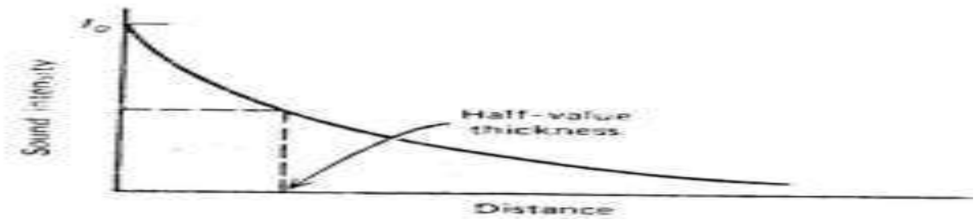


Figure Absorption of ultrasound

Where (I_o) is the incident intensity at **(X = 0)** and (I) is intensity at a depth (**X) ,** **(2α)** absorption coefficient . The half-value thickness (HVT) is the tissue thickness needed to decrease (I_o to $I_o / 2$) .

$A = A_o\, e^{-\alpha x}$

H.W what is the wavelength of a (1000 Hz) sound wave in water if its velocity in water is (1480 m/sec) ?

H.W what is the maximum displacement in air for a (1000 Hz) sound wave with an intensity of (50 dB or 10^{-7} W/m^2) ?

H.W if your loudest shout is (1000) times more intense than your normal speaking voice , what is the dB difference between them?

H.W calculate the relative pressure amplitudes of the reflected and transmitted waves from fat to muscle using the acoustic impedances given in table 12-1?

H.W what is the attenuation of sound intensity in (15 cm) of brain tissue ?