Sound in Medicine

GENERANL 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(Fig 1). 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.

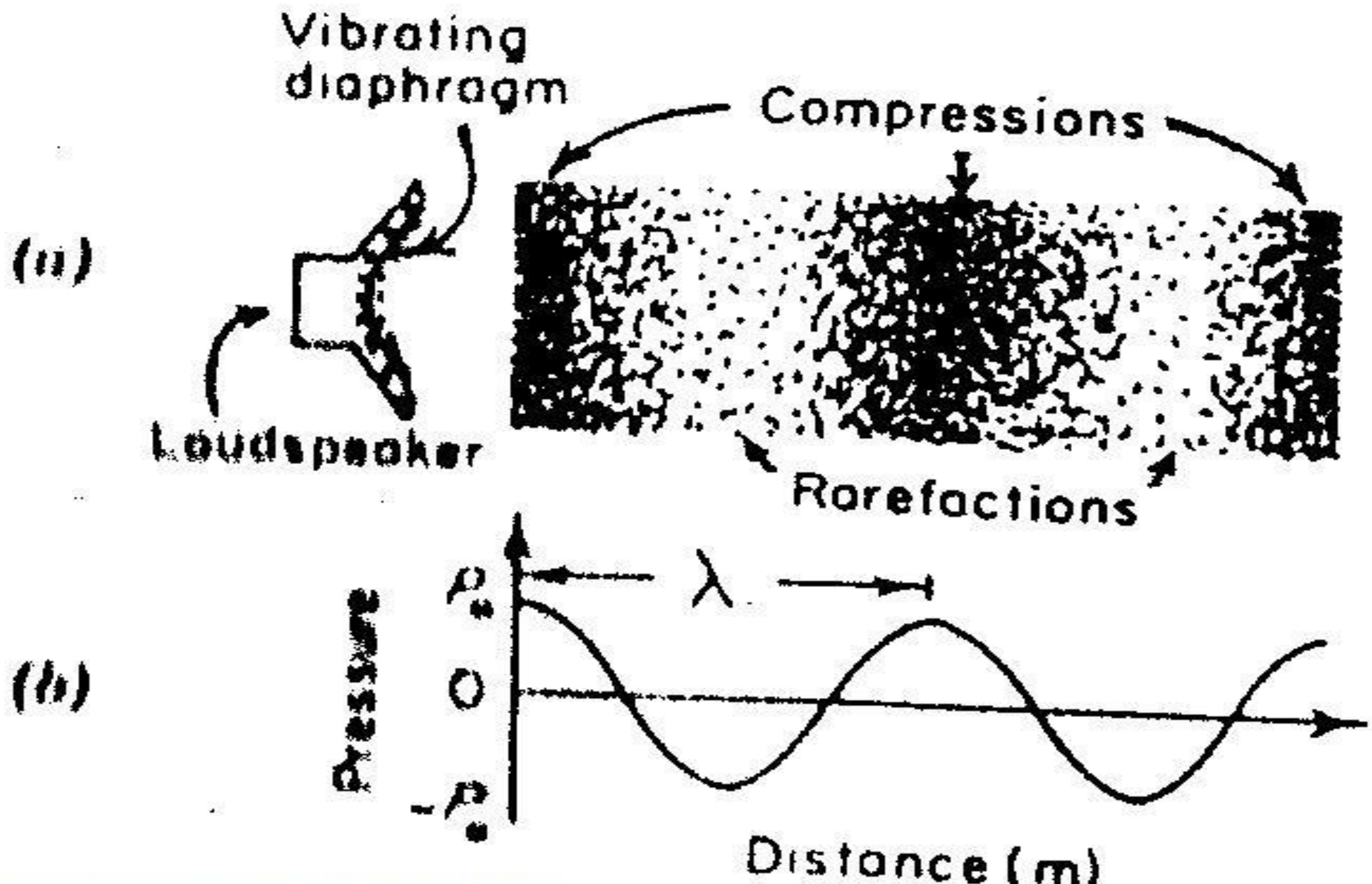


Fig.1. (a) A diaphragm vibrates, (b) A wavelenght

The compressions and rarefactions can also be described by density changes and by displacement of atoms and molecules from their equilibriums positions.

The relationship between the frequency of vibration **f** , the wavelength **λ**, and velocity **V** of the sound wave is

$$\mathbf{V = \lambda f}$$

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/m²**. What is the maximum displacement in air corresponding to this intensity?

sol

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

b.Calculate the sound pressure

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

= 29 N/m^2 =0.0003 Atmosphere

For comparing the intensities of two waves **(I_2/ I_1)**. This was named a after Alexander bell. The intensity ratio in bels equal to **$\log_{10}(I_2/ I_1)$**, and **(1 bel= 10 dB)** it is common to use the decibel comparing two sound intensities. Since I is proportional to P2, 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 we 2 get

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

This variation would not be noticed by the average ear except under controlled laboratory conditions.

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

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

H.w

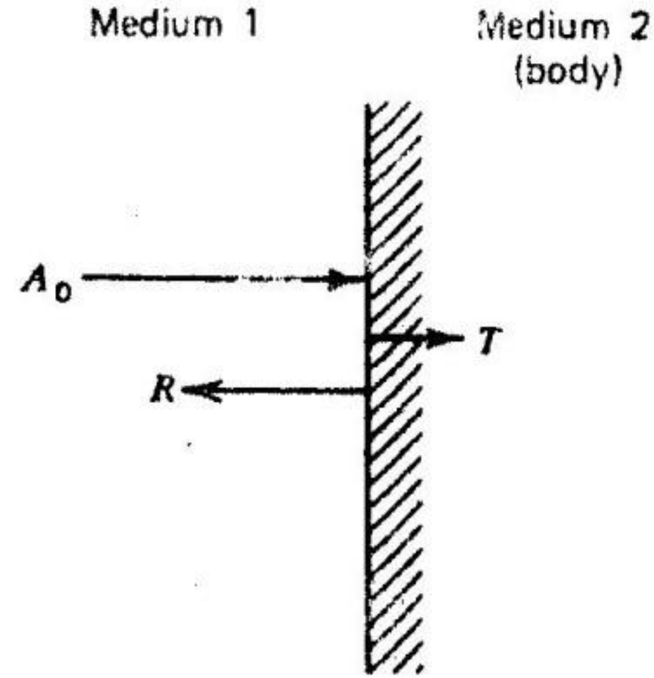
The sound intensity levels of $10^4 W/m^2$ can cause damage of the eardrum diaphragm. What is the displacement of the diaphragm at such intensity adopting an average frequency 1000Hz? Where the acoustic impedance for tissue equal $1.64x10^4 Kg/m^2s$.

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

- **R** : is the reflected pressure amplitude
- **A_o** :is the incident pressure amplitude

The ratio of **R/A_o** depends on acoustic impedance of the two media, **Z_1** and **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, Z1 is the acoustic impedance of air and Z2 is the a acoustic impedance of tissue.

If $\mathbf{Z_1 = Z_2}$

There is no reflected wave and transmission to the sound 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 **A_o** 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.

$$= \frac{1.64\ x\ 10^{6} - 430}{1.64\ x\ 10^{6} + 430}\ R/A_0$$

$$= \quad 0.9995$$

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

$$\doteq \ 1.9995$$

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 sound medium.

choosing materials with similar acoustic impedance is called impedance matching. Getting sound energy into the body requires impedance matching.

Calculate the amplitudes and intensities of the reflected and transmitted sound waves from water to muscle using the values from Table

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

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

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 Ɵi to a boundary between two media

$$\frac{\boldsymbol{sin}\Theta_1}{\boldsymbol{V}_1} = \frac{\boldsymbol{sin}\Theta_2}{\boldsymbol{V}_2}$$

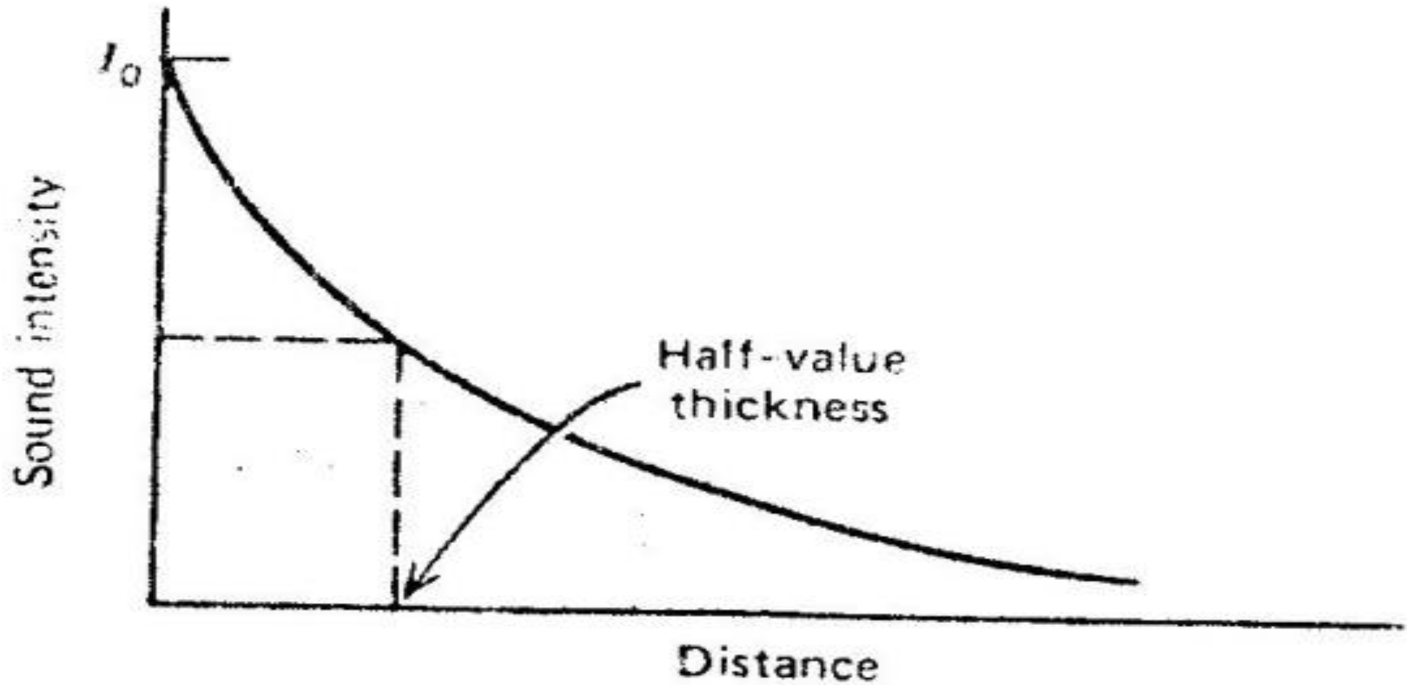
$\mathbf{V_1}$ and $\mathbf{V_2}$ are the velocities of sound in two media, $\boldsymbol{\Theta_1}$ is the angle of the incident wave, $\boldsymbol{\Theta_2}$ is the angle of the refracted sound wave. Because sound can be refracted, acoustic lenses can be constructed to focus sound waves.

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

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

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

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



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.**

Example

What is the attenuation of sound intensity by 1 cm of bone at 0.8, 1, 2, and 1.6 MHz?

-AT 0.8 MHz, the HVT is 0.34 cm, there for 1 cm is about 3 HVT and intensity is reduced by 2^3, or by factor 8 (ie ~ 12% remains).

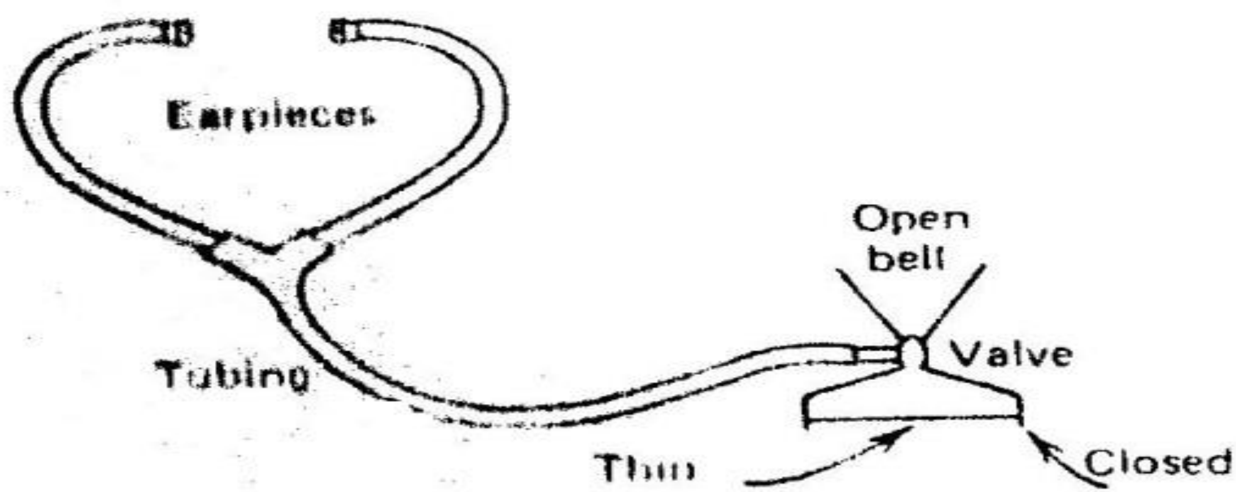
-AT 1.2 MHZ, the HVT is 0.21: 1 cm is nearly 5 HVT, and intensity is reduced by almost 25, or by factor 3^2 (ie ~ 3%).

-AT 1.6 MHz, the HVT is 0.11 cm : 1 cm is about 9HVT, and intensity is reduced by 2^9, or by factor of 512 (ie ~ 0.9%) remains.

THE STETHOSCOPE

The act of listening sounds with a stethoscope is called mediate auscultation or usually just auscultation.

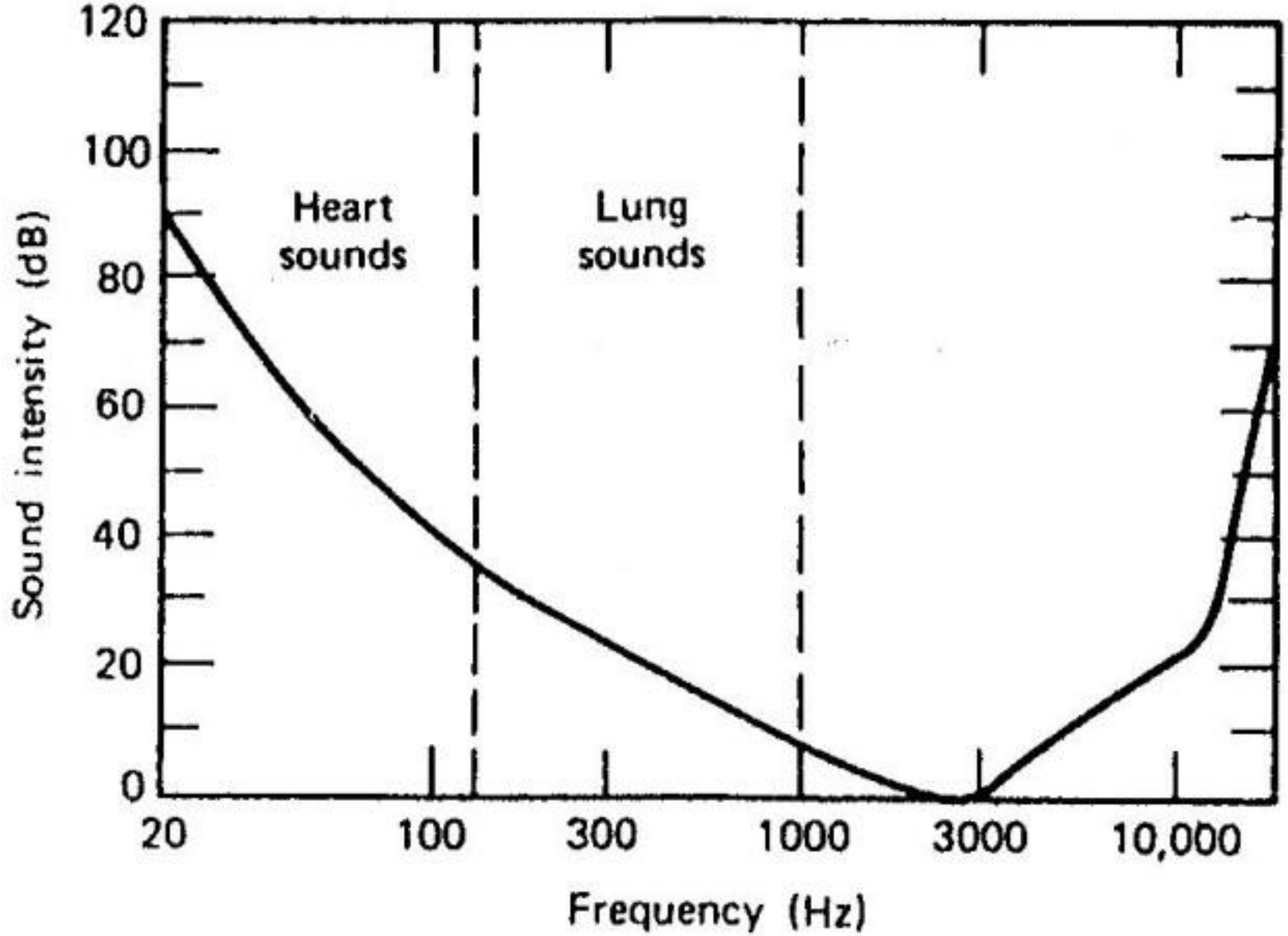
The main parts of a modern stethoscope are bell, which is either open or closed by a thin diaphragm, the tubing and the earpieces.



The open bell is an impedance matcher between the skin and the air and accumulates sounds from the contacted area. The skin under the open bell behaves like a diaphragm. The skin diaphragm has a natural resonant frequency at which it most effectively transmits sound; it is possible to enhance the sound range of interest by changing the bell size and varying the pressure of the bell against the skin and the skin tension.

A low frequency heart murmur will appear to go away if the stethoscope is pressed hard against the skin.

A closed bell is merely a bell with a diaphragm of known resonant frequency, usually high, that tunes out-low frequency sound, it is resonant frequency is controlled by the same factors that control the frequency of the open bell pressed against the skin. The closed bell stethoscope is primarily used for listening to lung sounds, which are of higher frequency ranges of heart and lung sounds.



120
100
80
60
40
20
0
Sound intensity (dB)
Heart
sounds
Lung
sounds
20
100
300
1000
3000
10,000
Frequency (Hz)

What is the best shape for the bell?

It is desirable to have a bell with as small a volume as possible.

The smaller the volume gas , the greater the pressure change for given movement of the diaphragm at the end of the bell.

The volume of tubes should also be small. And there should be little frictional loss of sound to the walls of the tube.

Below about 100 Hz tube length does not greatly affect the efficiency. But above this frequency decreases as the tube is lengthened.