Ministry of Higher Education and Scientific Research
Al-Mustaqbal University College
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Radiation Physics-2

Al-Mustaqbal University College

3rd

Radiology Techniques Department

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Lecture 1: Ultrasound Physics

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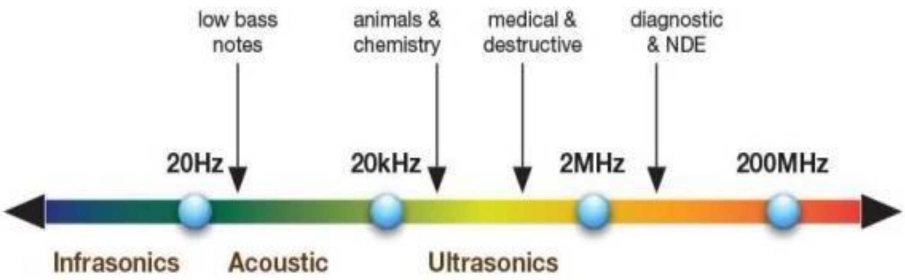
Introduction

Early, primitive display modes, such as A-mode and static B-mode, borrowed from metallurgical testing and radar technologies of the time, have given way to high-performance, real-time imaging.

Modern ultrasound systems are able to make detailed measurements of blood movements in blood vessels and tissues, visualize moving structures in 3D, and make measurements related to the stiff ness of tissues.

- Humans can hear sound waves with frequencies between 20 Hz and 20 KHz
- Ultrasound: > 20 KHz
- Diagnostic medical ultrasound typically uses transducers with a frequency between 1-20 MHz



Sound Waves (vibrations)	X-Ray
Mechanical wave	Electromagnetic radiation
longitudinal waves	Transverse waves
These vibrations, back and forth, occur along the line of travel of the sound wave	Electric and magnetic component perpendicular to each other
The speed of sound varies depending on the medium it is propagating through	Velocity is constant (the velocity of light 3×10^{8} m/s

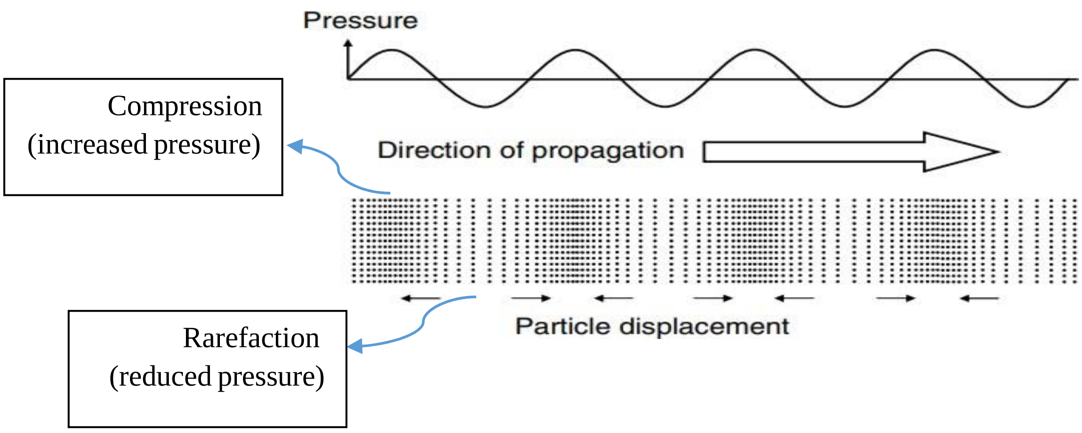
- **A wave** is a disturbance with a regularly repeating pattern, which travels from one point to another.

The major advantages of ultrasound diagnostic methods over alternative procedures are its attributes of :

1. Non-Invasiveness
2. Lack of any known side effects, either immediate or long-term ,
3. No associated discomfort to the patient ,
4. Relative cheapness.
5. Safe in pregnancy
6. Portable

Frequency, Velocity and wavelength

The sound waves used to form medical images are longitudinal waves, which propagate (travel) through a physical medium (usually tissue or liquid)



The frequency of the wave The number of complete cycles in a unit of time is the frequency (f) of the sound.

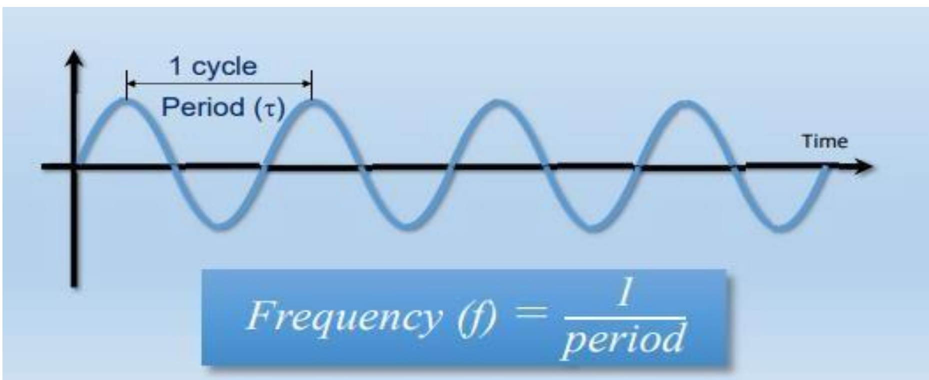
Frequency and period are inversely related.

The wavelength of a wave is the distance between consecutive wave crests or other similar points on the wave

One hertz (Hz) =one cycle per second

Frequency u × time = number of cycles

Frequency u × 1 period = 1 cycle



Wavelength is proportional to velocity (the wave equation)

$$c = u \, . \, \lambda$$

EX: Propagation velocity in the heart is 1540 m/s, the wavelength for any transducer frequency can be calculated as:

$$\lambda = 1540/\, u \; (MHZ)$$

Table 3: Velocity of sound in human tissues and liquids

Material	c (m s^{-1})
Liver	1578
Kidney	1560
Amniotic fluid	1534
Fat	1430
Average tissue	1540
Water	1480
Bone	3190–3406
Air	333

The speed of sound is affected by the density and stiffness of the material:

$$C = \sqrt{K/\rho}$$

High velocity of sound = high stiffness and low density

Low velocity of sound = low stiffness and high density

Where k = stiffness, ρ = density

Frequencies and wavelengths used in diagnosis

The ultrasound frequencies used most commonly in medical diagnosis are in the range 2–15 MHz, although frequencies up to 40 MHz may be used in special applications and in research.

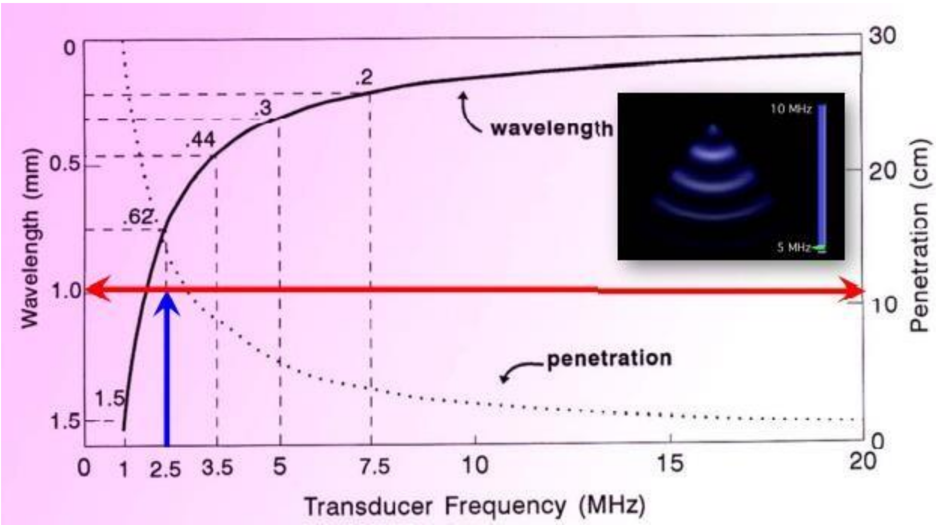
- Assuming the average speed of sound in soft tissues of 1540 m s $^{-1}$, values of λ at diagnostic frequencies are as shown in Table 2 .

Table 2: Wavelengths used in diagnosis.

f (MHz)	λ (mm)
2	0.77
5	0.31
10	0.15
15	0.1

The wavelength of the ultrasound wave has an important influence on the ability of the imaging system to resolve fine anatomical detail. Short wavelengths give rise to improved resolution, i.e. the ability to show closely spaced targets separately in the image.

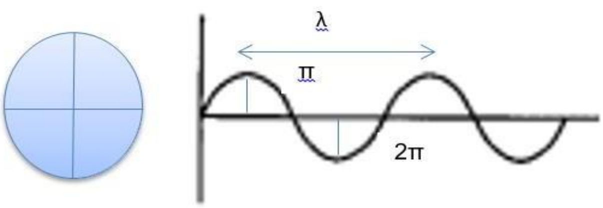
Wavelength vs. Penetration



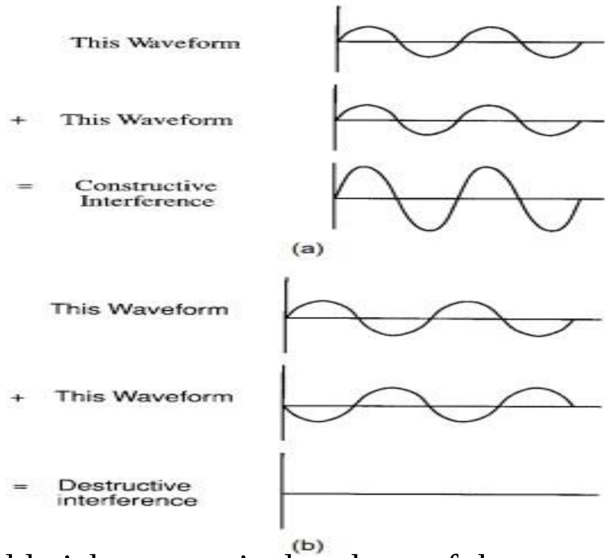
(H.W) If the frequency of a vibrating particle is 400 hertz, and the speed of sound in air is 320 m/s. Find the distance traveled by the sound produced by the particle's vibration when the particle has completed only 30 vibrations?

Phase Velocity and Group Velocity

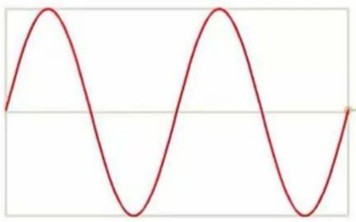
There are two different fundamental sound velocities we must distinguish between them: the group velocity and the phase velocity:



❖ Waves can exhibit interference, which in extreme cases of constructive and destructive interference leads to complete addition (a) or complete cancellation (b) of the two waves.



❖ You could pick one particular phase of the wave (for example the crest) and it would appear to travel at the phase velocity.



The phase velocity of a wave is the speed at which a given phase of a wave travels through space. The phase velocity of a wave is the rate at which the phase of the wave propagates in space.

phase velocity is defined as

$$V_p=\omega/k$$

A propagating medium is said to be dispersive if the phase velocity is a function of frequency or wavelength. This means that the different frequencies contained in the signal do not propagate at constant velocities.

The group velocity is the speed of the overall shape of a modulated wave (called the envelope). The group velocity of a wave is the rate that changes in amplitude (known as the envelope of the wave) will propagate through space.

The group velocity v_p is given by

$$V_g=d\omega/dk$$