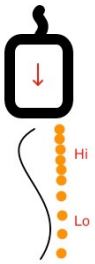
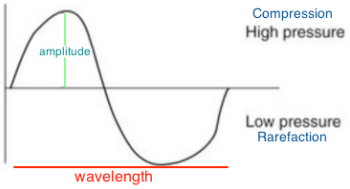
Ultrasound Physics Review

Physics principles (15%)

Properties of sound



Sound is a mechanical, longitudinal wave. Longitudinal means parallel from sound source. Mechanically moves through medium by vibration of molecules or physically changing pressure, compressions (high pressure) and rarefactions (low pressure)
One complete cycle = 1 compression and 1 rarefaction

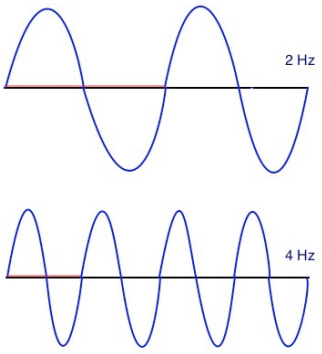


Frequency	# cycles per second	**Hz**
Wavelength	length of one cycle	**mm**
Period	time of one cycle	**μs**

$$\lambda = \frac{c}{f}$$

λ = wavelength
c = prop speed
f = frequency

Relationships
Direct: If one increases, the other increases and vice versa (go together)
Inverse: If one increases, the other decreases (opposites)



Wavelength depends on 2 things - frequency (*determined sound source)* and propagation speed *(determined by medium)*

Wavelength and frequency are **inversely related**
Wavelength **directly related** to propagation speed

Mediums with fast prop speed = longer wavelength
Mediums with slower prop speed = shorter wavelength
Propagation speed is NOT affected by either freq or wavelength

Think about the terms! Physics is very literal. If you do not know what something means, think about what it means in everyday language.
Example: frequency means how often something happens in a period of time. So in ultrasound, it means how many waves occur in one second

Different types of sound

- Infrasound < 20 Hz
- Audible sound 20-20,000 Hz
- Ultrasound >20,000 Hz
- Diagnostic US 2-20 MHz

Common unit prefixes

kila(k) = thousand
mega(M) = million
centi(c) = 1/100
milli(m) = 1/1,000
micro(**μ**) = 1/1,000,000

Simply exchange the word with the prefix
Example: 20,000 Hz = 20kHz

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Measuring energy

Power- rate of flow of energy (Watts)

Intensity- power/area (Watts/cm^2)

Example: 40 Watt light bulb. That's power. Imagine the 40W bulb in a small closet vs it in a large room. Which appears more intense? The closet = smaller space = greater intensity. Increase the space = decreases the intensity

Amplitude- *height* of pressure wave (MPa megapascals). Hydrophone: used to measure the profile of US beam by measuring the pressure amplitudes (intensities)

These describe the strength of the energy. These are NOT related to frequency/wavelength/period.

Decibels

In US, we use deciBels to describe the relative intensity of our wave.
We only care about what happened to the intensity, not the value.
In other words, to describe HOW much our intensity has changed, we use deciBels.

When we multiply our intensity by 2 = rise of 3 dB (increase or gain)

If we half the intensity = loss of 3 dB (decrease or attenuation)

Half-value layer= when sound reaches 1/2 its original intensity = **-3dB**

Intensity	Decibels
1000	30
100	20
10	10
4	**6**
2	**3**
1	**0**
1/2	**-3**
1/4	**-6**
1/10	-10
1/100	-20
1/1000	-30

Q: A reduction of 6dB means the intensity is reduced by how much?
(we will see more about dB affects us when we look at attenuation)

A: Losing 6 dB corresponds to intensity reduced to 1/4. So if sound attenuated 6dB, that means it is now 25% what is was originally

Q: Adjusting overall gain from 25dB to 28dB will cause what affect to the intensity of the echoes?

A: There was an increase of 3dB which means the intensity was doubled.

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Properties of the Medium

Propagation speed

Speed of sound in a medium. **Totally dependent on medium only.**

Before we discuss how sound interacts with the tissue, we have to first understand the properties of our tissue. So forget about sound for a moment.
Propagation speed is a property of the medium. It will only change if the medium changes.

In soft tissue ☞ 1.54 mm/μs or 1540 m/s ALWAYS

It is based on a mediums stiffness (how hard) and density (how packed together) Stiffness is same as BULK MODULUS. Each medium has its own propagation speed.

Elasticity and Compressibility

Opposite to stiffness!
Think of something elastic and compressible.
Ex- marshmallows are very compressible and NOT stiff.
So if elasticity increases > stiffness decreases

⬆ stiffness	⬆ prop speed
⬆ bulk modulus	⬆ prop speed
⬆ compressibility	⬇ prop speed
⬆ elasticity	⬇ prop speed

Propagation speed is NOT affected by frequency or wavelength

$$c = \sqrt{\frac{\text{stiffness}}{\text{density}}}$$

Based on the formula, technically density and prop speed are inversely related. But generally, mediums that are dense are also more stiff, that means prop speed increases.

Medium	Density	Prop Speed
Air	1.2	330
Fat	920	1450
Water	1000	1484
Liver	1060	1570
Muscle	1070	1580
Bone	1800	4080

Increasing propagation speed

Increasing density

Increasing wavelengths

Each medium also has its own **IMPEDANCE** value. To impede means to obstruct or hinder.

∴ Impedance is a measure of resistance (Rayls). It is a property of the medium, so …
It is only dependent on the medium.

Z = pc

Z = impedance
p = density
c = propagation speed

⬆density	⬆impedance
⬆prop speed	⬆impedance

Impedance is NOT affected by frequency or wavelength