Sononerds
in the classroom

ARDMS Topic:
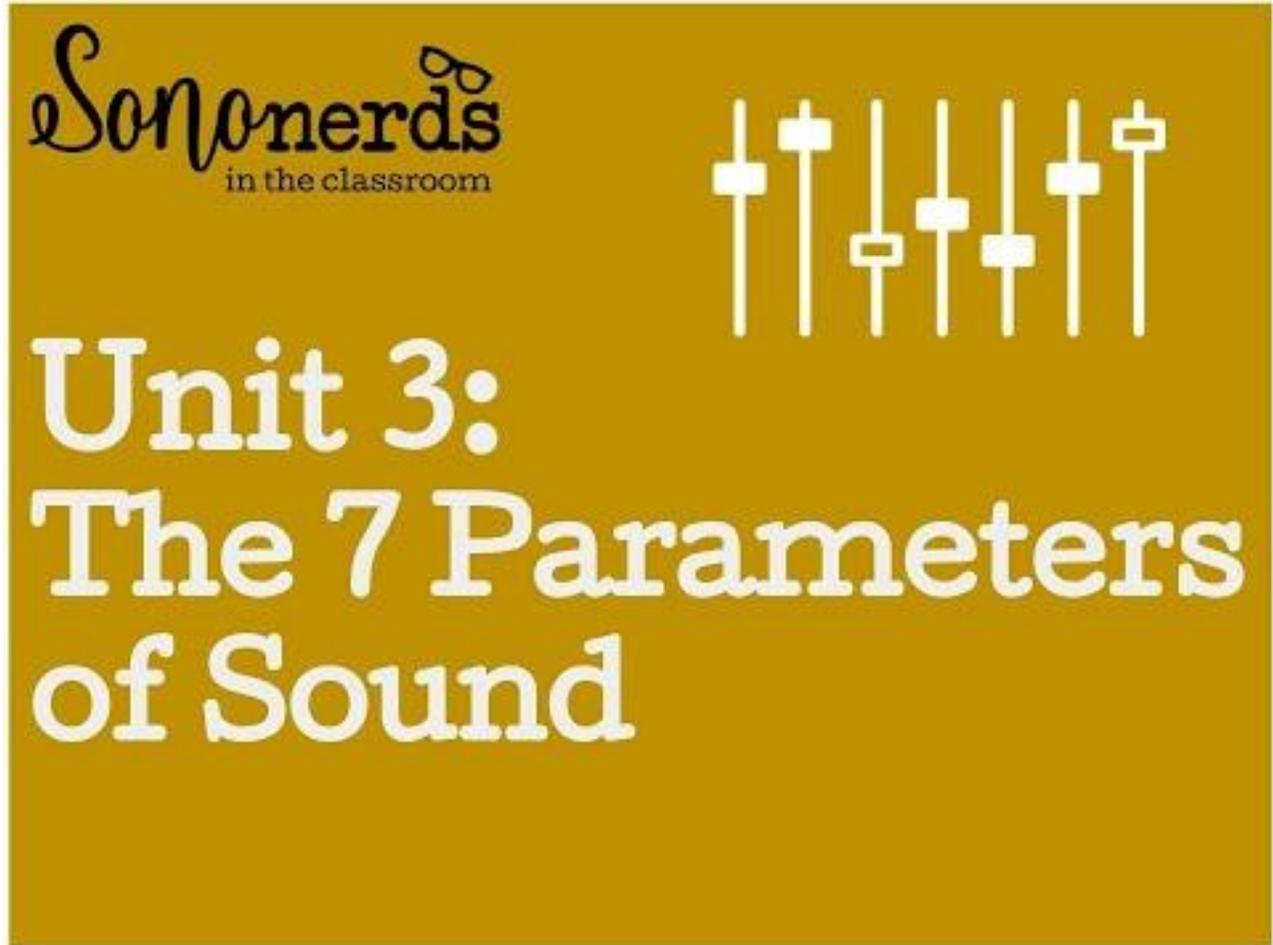**Ultrasound Physical Principles**

Unit 3:   The Seven Parameters of Sound

Sononerds Ultrasound Physics
Workbook & Lectures

Unit 3: The Seven Parameters of Sound

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Unit 3: The Seven Parameters of Sound

[Entire Unit 3 Lecture](#):

Some interesting links:

https://www.physicsclassroom.com/Physics-Interactives/Waves-and-Sound/Simple-Wave-Simulator/Simple-Wave-Simulator-Interactive

https://phet.colorado.edu/sims/html/wave-on-a-string/latest/wave-on-a-string_en.html

Unit 3: The Seven Parameters of Sound

All sound waves (including ultrasound) have certain characteristics that have measurable quantities. These measurable characteristics are called **parameters** and define the sound wave from which they were obtained..

There are seven parameters of sound waves that you will need to know:

→ **Frequency**
→ **Period**
→ **Propagation Speed**
→ **Wavelength**
→ **Amplitude**
→ **Power**
→ **Intensity**

For each parameter, you should know:

→ **Definition & Synonyms**
→ **Units**
→ **Symbol**
→ **Formulas & Relationships**
→ **Sonographer Impact**

You will see the sinusoidal graphs used in this chapter to visually represent some of these parameters. The graphs will look VERY similar, so always pay attention to the labeled units!
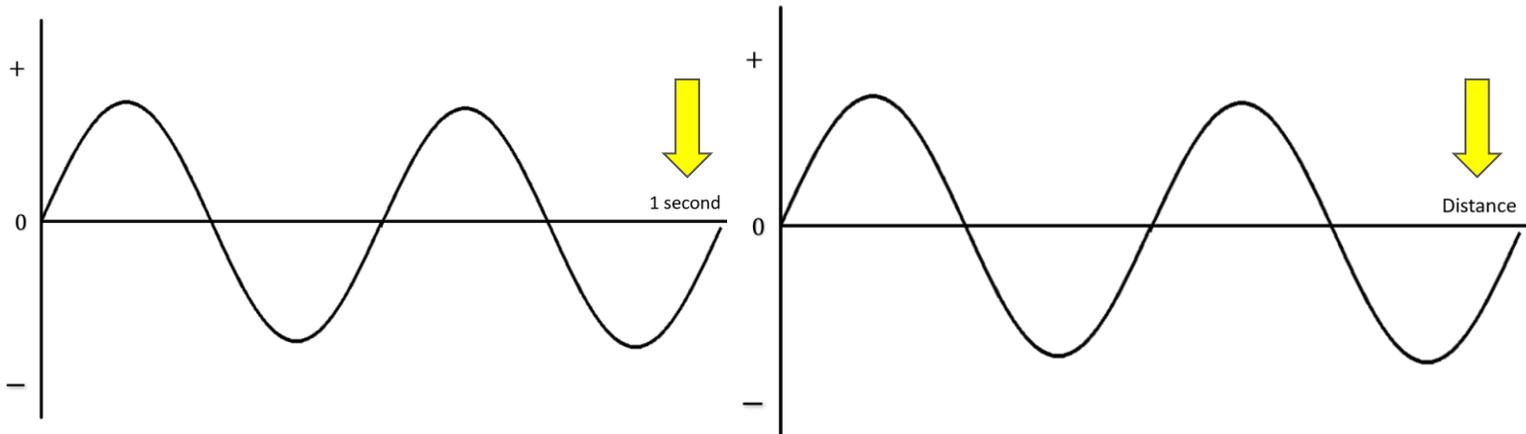
Section 3.1 Period & Frequency

Period and frequency are closely related. Do you remember their special relationship to one another?

They are reciprocals! That means that when period and frequency are multiplied together, they equal 1.

Both period and frequency are defined partially by the concept of a cycle.

A **cycle or wavelength**, is one complete oscillation. If we could follow one tiny little particle, we would see the particle start at Resting → Compression → Resting → Rarefaction → and back to Resting
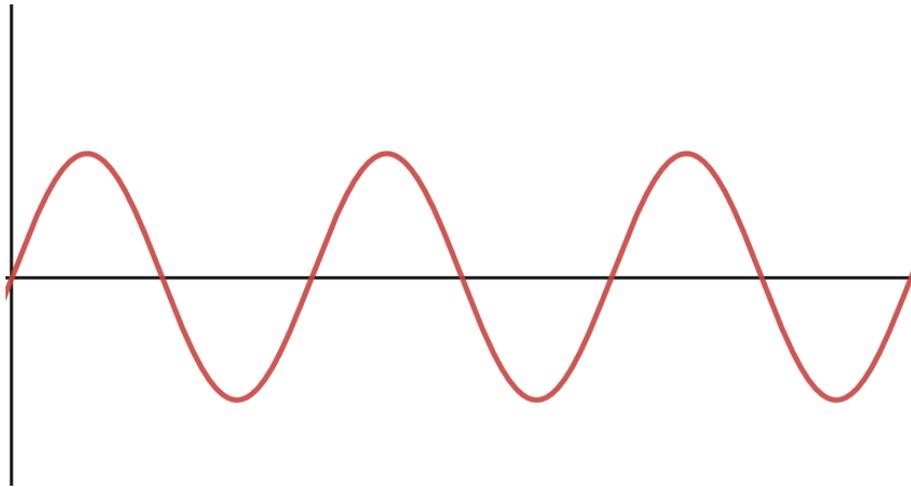
And that would complete a cycle.

Rarefaction   Resting   Compression
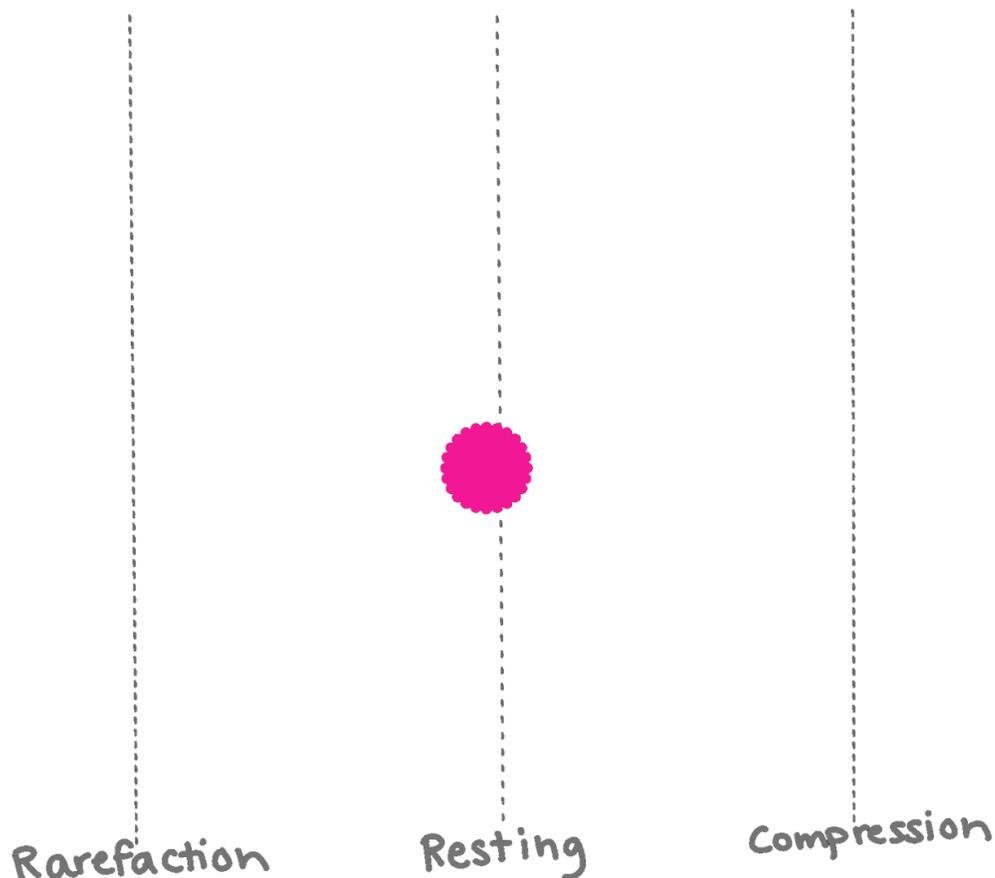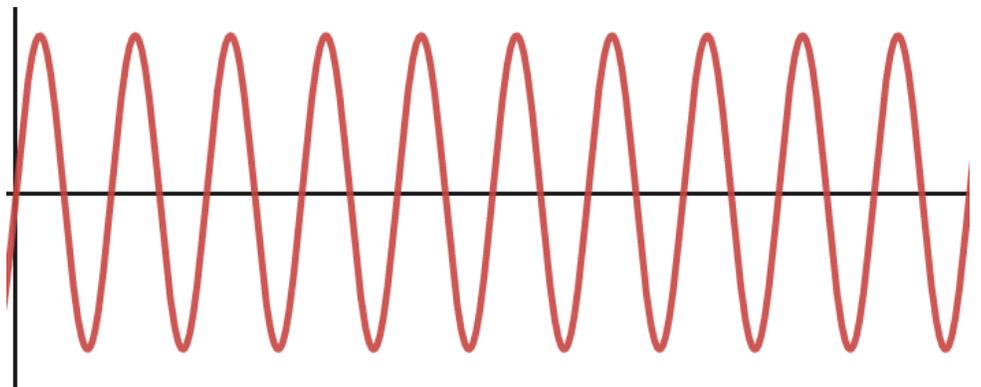
On a graph, for ease, we typically go:

Baseline → Peak → Baseline → Trough → Baseline
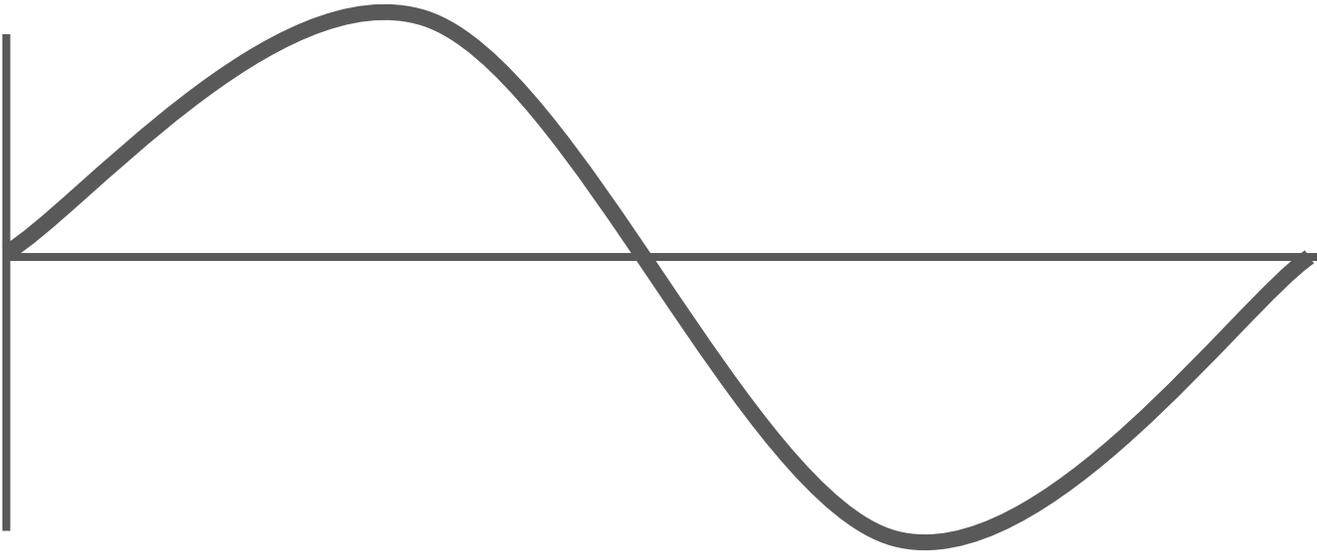
This image show 3 cycles:

And this one has 10 cycles:

3.1.1 Period

Definition

The **time** it takes to complete one cycle.

Period is the time it takes for one cycle. Another way to think of it is the time it takes for an entire event. For example, for the earth to rotate once, all the way around, is one day. So the period of earth's rotation is one day, 24 hours, 1/365 of a year, etc.

Symbol	Units
T	Microseconds (µs) or any time unit. Period is expressed in a unit of time, typically microseconds as it is complementary to the frequency unit of megahertz. The average ultrasound value for period is 0.06 to 0.5 microseconds

| Formulas	Relationships
$$T(\mu s) = \frac{1}{f\ (MHz)}$$ $$\uparrow T \Leftrightarrow \downarrow f \quad \downarrow T \Leftrightarrow \uparrow f$$	<u>Period and Frequency are inversely related (reciprocals):</u> If period gets longer → Frequency gets lower If period gets shorter → Frequency gets higher

Sonographer Impact

Period is determined by the machine.
It cannot be changed by the sonographer.

Period is innate to the transducer and frequency chosen. There is not a knob on the machine labeled "period" that the sonographer can adjust. The period of a wave factors into other imaging considerations.

Period answers the question:

How long does it take for one cycle to occur?

1 second?
1 microsecond?
5 seconds?
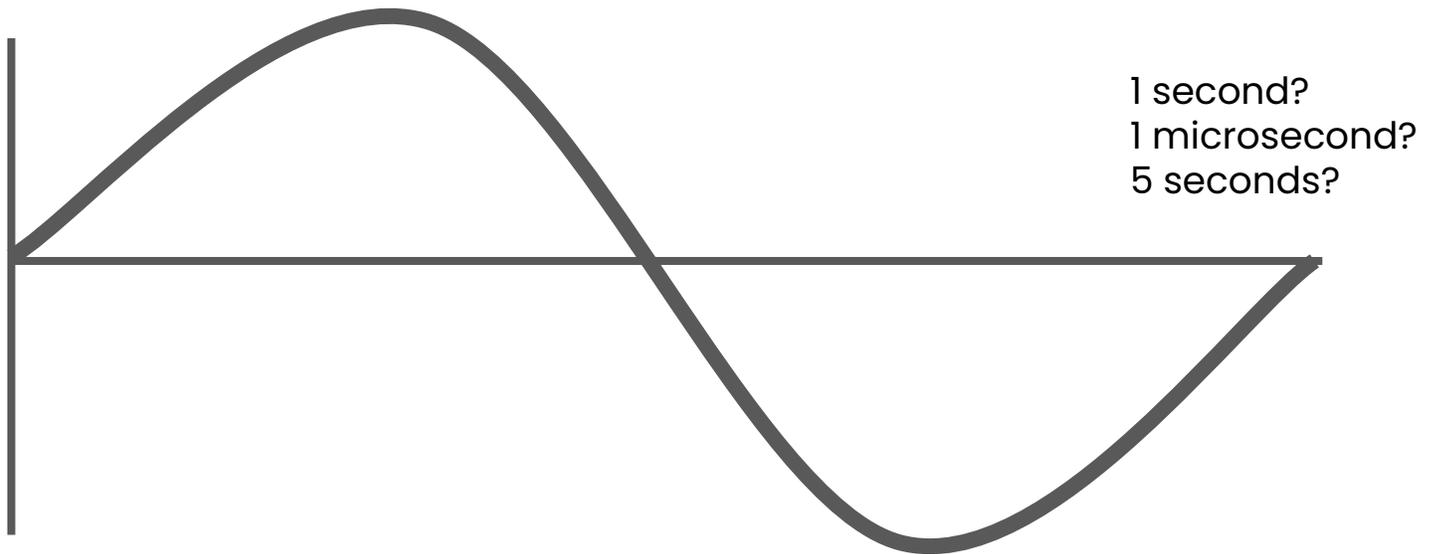
Example:
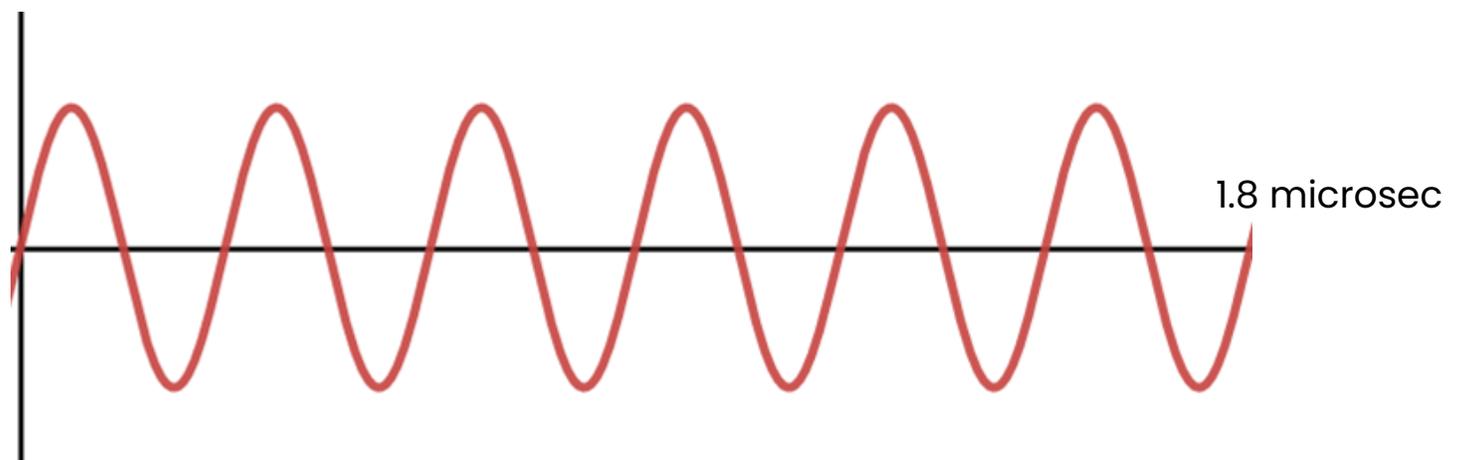
1.8 microsec

There are 6 cycles represented in this graph labeled at 1.8 microseconds. The period of each cycle is 0.3 microseconds.

To calculate the period based on graph, count the # of cycles. Divide the time frame by the # of cycles. (1.8 / 6 = 0.3)

0.3 µs   0.3 µs   0.3 µs   0.3 µs   0.3 µs   0.3 µs

3.1.2 Frequency

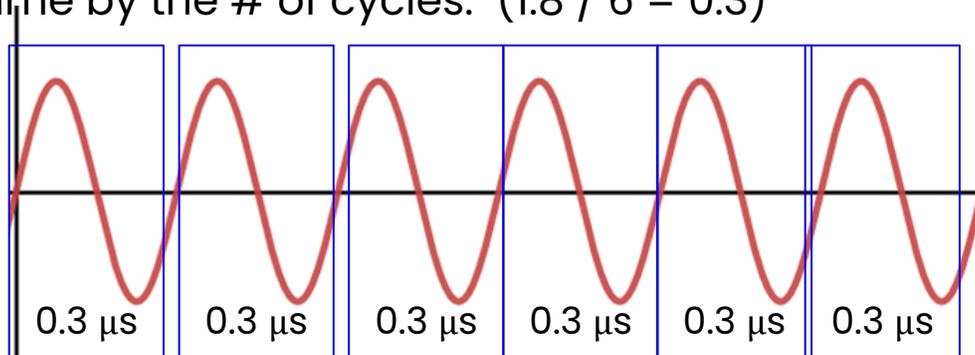| Definition	
The number of cycles per **second (or ms or μs)** Frequency, in general, is how often an event occurs and is expressed as events per time length. For example, beats per minute is a frequency, so is once per day. The frequency of filing taxes is once per year for many people. In regards to waves though, frequency is specifically the number of cycles per second.	

Symbol	Units
f	Hertz (Hz), Kilohertz (kHz) or Megahertz (MHz) There are many types of frequencies related to ultrasound. However, the average ultrasound value of the transducer frequency is between 2 MHz and 15 MHz. (But as low as 1 MHz and up to 17 MHz are commonly used!)

Formulas	Relationships
$f\ (MHz) = \dfrac{1}{T\ (\mu s)}$ $\uparrow f \Leftrightarrow \downarrow T \quad \downarrow f \Leftrightarrow \uparrow T$ $f\ (MHz) = \dfrac{c\ (mm/\mu s)}{\lambda\ (mm)}$ $\uparrow f \Leftrightarrow \downarrow \lambda \quad \downarrow f \Leftrightarrow \uparrow \lambda$	<u>Frequency & Period are reciprocals:</u> If frequency gets higher → Period gets shorter If frequency gets lower → Period gets longer <u>Frequency & Wavelength are inversely related:</u> If frequency gets higher → wavelength gets shorter If frequency gets lower → wavelength gets longer

Sonographer Impact	
Frequency is determined by the machine/transducer. The sonographer cannot adjust frequency. *(more on this)* The sonographer should choose the appropriate frequency for the exam.	

Using Hertz as a unit for frequency:

Hertz means events per **second**. We can use derivatives of Hertz to express frequency because:

- 1 Hz = 1 cycle per second
- 1 kHz = 1 000 cycles per second
- 1 MHz = 1 000 000 cycles per second

Watch the labels on graphical representations of waves. It would be really hard to draw a true 5 MHz wave on paperif the time frame was always 1 second.So we can change the representation by changing the labeled time frame.

Frequency and pitch:

Low frequencies have lower pitches, where high frequencies have high pitches. There is a range of frequencies that are audible to the human ear. There are also frequencies that are too low to hear (infrasound) and frequencies that are too high to hear (ultrasound!!!). Although ultrasound is anything about the audible range, remember that diagnostic imaging is typically in the range of 1 to 17 MHz.

- → **Ultrasound (above audible) is > 20 kHz**
- → **Sound (audible) is 20 Hz – 20kHz**
- → **Infrasound (below audible) is <20 Hz**

We can't adjust frequency, but...

No, we cannot change frequency. So then why do you have a button on your modern machine that says you can? Good question. Old machines had transducers with limited bandwidth. If you wanted to use a low frequency for an image, you had to use your low frequency transducer. If you needed better resolution, then you needed to change to a new higher frequency transducer.

Modern transducers have larger bandwidth, this means that when they emit a sound beam, the sound beam contains many frequencies. For example a linear 12-5 transducer emits frequencies between 5 MHz and 12 MHz (all at once!)

The 12 MHz frequency will return 12 MHz echoes, the 7 MHz frequency will return 7 MHz echoes and so on… As a sonographer, you can tell the machine to listen for the 12 MHz frequencies, when you need more detail or you can tell the machine to listen for the 5 MHz frequencies when you need more depth.

If you are asked if a sonographer can adjust frequency, you should say no…think of it more as "can you change the frequency of a transducer?" Transducers are made the way they are made and you need to select a new transducer to get new frequencies.

Why do we have different frequency transducers?

We are going to learn a lot about frequency throughout the book, but one of your biggest roles as a sonographer is to understand why you are making the choices you make based on ultrasound physics.

Frequency is a big one. We must balance the want for detail resolution with the need for diagnostic images.

A transducer capable of a frequency range of 12 MHz to 5 MHz will show very detailed images of anatomy, but can only image a few centimeters into the body.

Compared to a transducer with a frequency range of 5 MHz to 1 MHz, the detail worsens, but now the low frequencies can image more than 20 cm into the body.

Seeing the anatomy in poorer detail is typically better than not seeing it at all. However, with all the transducer available, we should aim to use the highest frequency possible, that allows for adequate visualization of the target anatomy.

Frequency answers the question:

How many cycles can occur in 1 second (or ms or μs)?

1 second?
1 ms?
1 μs?
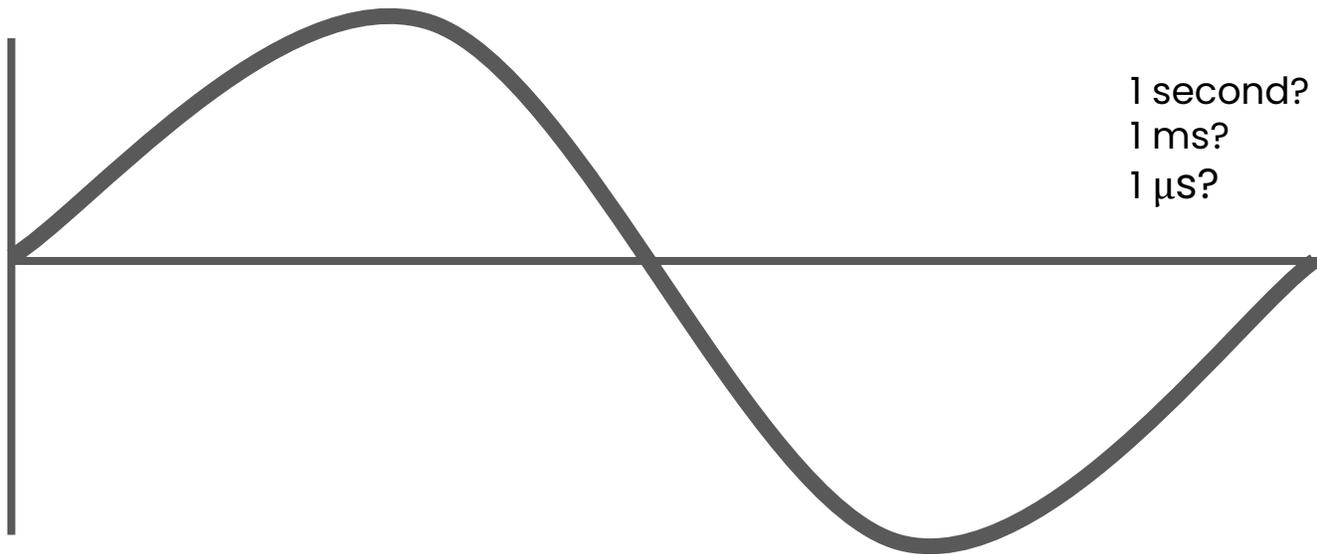
Example:
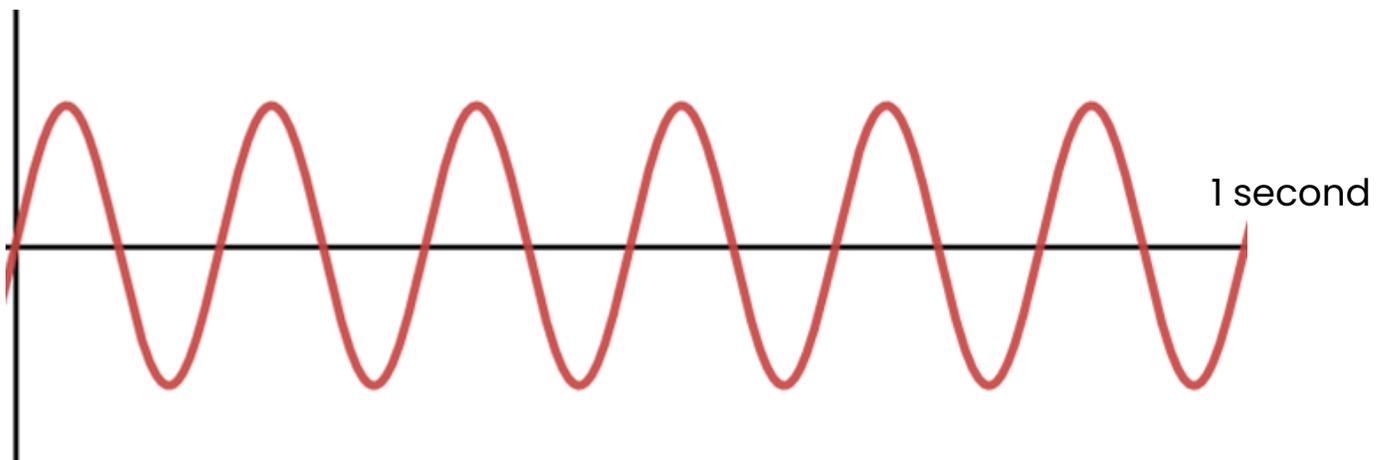
1 second

There are 6 cycles represented in this graph labeled 1 second. The frequency is 6 cycles per second or 6 Hertz.

To calculate frequency from a graph, count the cycles that can occur in one second.

2 seconds

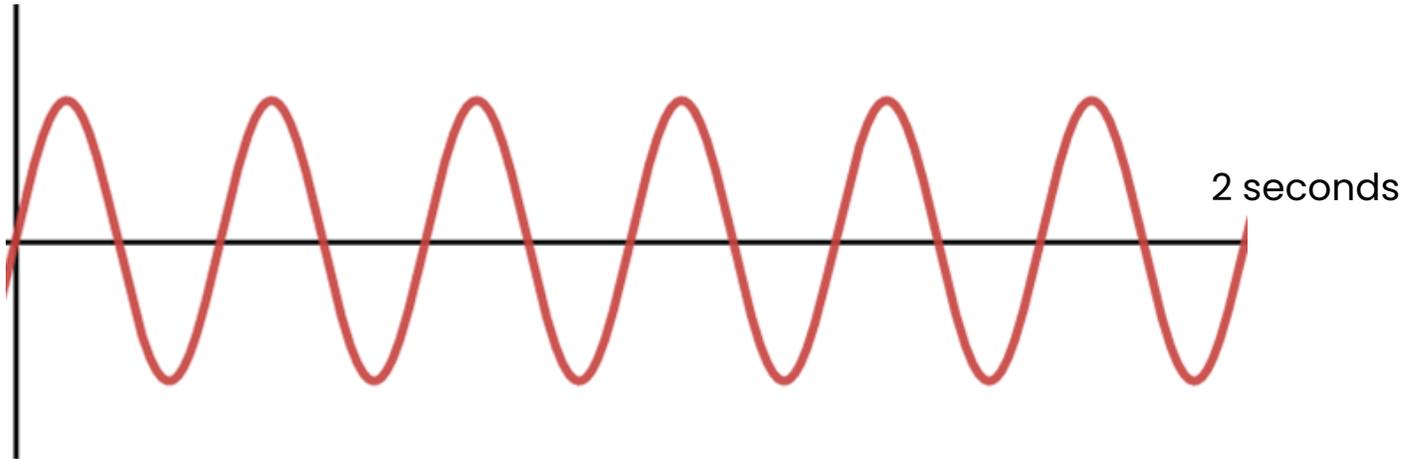Watch your labels though! This graph is labeled at 2 seconds. You may want to just count the cycles and say it is 6 Hertz, but in reality it is 6 cycles / 2 seconds. We need to reduce this to 3 cycles / second . This graph is showing a wave with a 3 Hertz frequency.

1 ms OR
1 microsecond
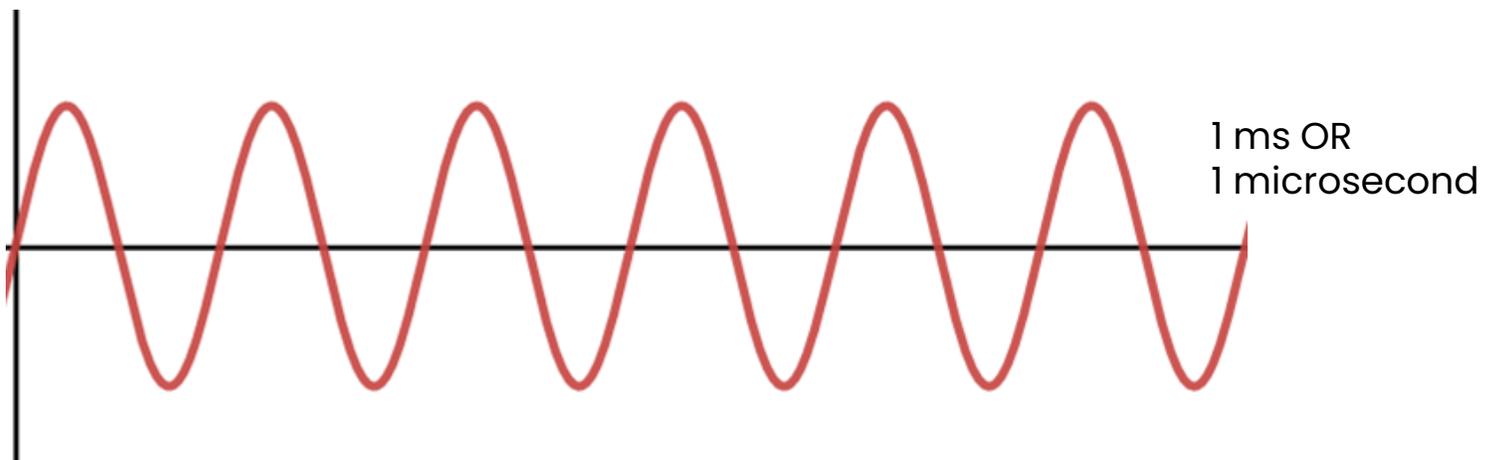
Note that we can also figure out frequency easily (and more applicable to ultrasound) if the graph is represented in milliseconds or microseconds.

For a graph labeled in **milliseconds**, we are seeing frequency in **kilohertz** (kHz). This graph is showing a 6 kHz wave.

For a graph labeled in **microseconds**, we are seeing a frequency in **megahertz** (MHz). This graph would be showing a 6 MHz wave.

3.1.3 Period and Frequency Review

Period and frequency are reciprocals and if you know one, you can calculate the other based on the formulas:

$$T(\mu s) = \frac{1}{f\ (MHz)} \qquad f\ (MHz) = \frac{1}{T\ (\mu s)}$$

If we are shown a graph like this:

We can count the number of cycles that occurred within one second to be 2. The frequency of this wave is 2 Hz.

Or we can divide one second by 2 cycles to figure out the period, which ½ second.
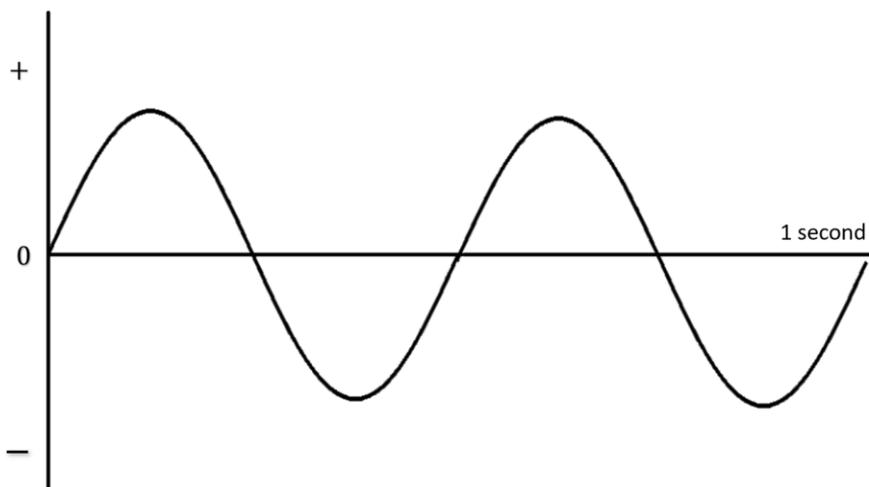
Sometimes though, you will only be given the frequency or the period, without a graph. You can calculate the missing information by using reciprocals and using complementary units.

3.1.3 Period and Frequency Review - Practice

Calculate the frequency or period for each pair. Watch units!

Period	Frequency	Period	Frequency
0.3 seconds			7 Hz
	10 MHz	0.2 microseconds	
5 seconds			3 MHz
	20 kHz	4 ms	

Bonus question Are these frequencies (A)udible, (I)nfrasound or (U)ltrasound??

Section 3.2 Wavelength & Propagation Speed

Section 3.1 told us that:

- Period & Frequency are reciprocals
- That both period and frequency are controlled by the machine/transducer
- Neither period or frequency can be adjusted by the sonographer.

In this section, we are going to see how wavelength and propagation speed share some similarities and then put all 4 parameters in relation to one another.

3.2.1 Propagation Speed

Definition	
The **speed** that a sound wave travels through a **medium**. Propagation speed is the rate at which a sound wave will travel through a medium. The only way speed changes is if the medium changes. ➜ All frequencies will travel at the **same** speed through any given medium.	

Symbol	**Units**
$$c$$	meters/second (m/s) or mm/microsecond (μs) In ultrasound, the body is made up of several types of mediums. Since we do not know what medium the sound is encountering at any moment, a soft tissue average was derived. The soft tissue average is **1540 m/s or 1.54 mm/μs.**

Formulas	**Relationships**
$$c = \frac{e \ (elasticity)}{\rho \ (density)}$$	Speed & Stiffness are directly related: If a medium is stiffer → speed is faster If a medium is more elastic→ speed is slower ➜ **Stiffness has a greater influence on propagation speed** Speed & Density are inversely related: If a medium is more dense→ speed is slower If a medium is less dense → speed is faster

Sonographer Impact	
Propagation speed is **only** determined by the medium. It cannot be adjusted by the sonographer, but you must know the average soft tissue speed and basic speed in other types of mediums	

Propagation speed answers the question:

How fast does sound travel through a medium?

The average "soft tissue" speed was derived by taking the known propagation speeds of biological tissue and averaging them together.

Medium	Speed (m/s)
Air	330
Lungs	500
Fat	1450
Water	1480
Soft Tissue	**1540**
Liver	1560
Blood	1560
Bone	4080

→ Know the order these go in or be able to reason it out. (Different sources cite different speed for some tissue. Air, water, Soft tissue & Liver were the most consistent)

→ **Ultrasound machines assume an average propagation speed of 1540 m/s or 1.54 mm/μs in soft tissue.**

What do density and stiffness mean?

→ **Stiffness** - is a medium's ability to resist compression. **Bulk Modulus** is another name for stiffness. Similar ideas, but with opposite meanings are **elasticity** and **compressibility.**
  ◆ A marshmallow has low stiffness, low bulk modulus, but high elasticity and high compressibility.
→ **Density** - is the mass per a volume. If something is very dense, it weighs a lot and takes up less space.
  ◆ A pound of feathers has low density compared to a pound of lead because the volume or space it takes up is HUGE compared to the compact and heavy lead.
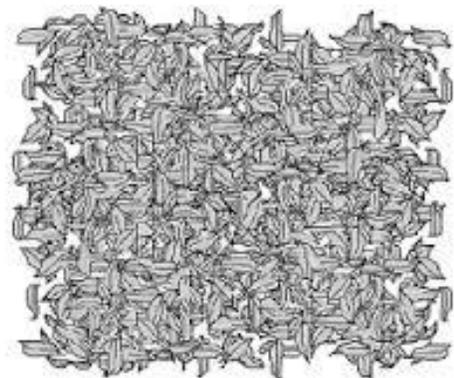
1 lb. lead   1 lb. feathers

3.2.2 Wavelength

Definition	
The **distance** a cycle takes up in space If we could get out a tiny little ruler and measure the sound wave from the start to the end of a cycle we would know the wavelength. Thankfully, wavelength, period and frequency are all related so we have formulas to help us with those calculations.	

Symbol	Units
Greek letter Lambda $$\lambda$$	Millimeters (mm) The the wavelength for clinically useful ultrasound is typically measured in millimeters and has an average value of 0.1 to 0.8 mm in **soft tissue**.

| Formulas	Relationships
$$\lambda\ (mm) = \frac{c\ (mm/\mu s)}{f\ (MHz)}$$ $\uparrow \lambda \Leftrightarrow \downarrow f \quad \downarrow \lambda \Leftrightarrow \uparrow f$ $\uparrow \lambda \Leftrightarrow \uparrow c \quad \downarrow \lambda \Leftrightarrow \downarrow c$ **In soft tissue:** $$\lambda\ (mm) = \frac{1.54\ (mm/\mu s)}{f\ (MHz)}$$	<u>Wavelength & Frequency are inversely related:</u> If a wavelength is longer → frequency is lower If a wavelength is shorter→ frequency is higher <u>Wavelength & Prop. Speed are directly related:</u> Wavelengths get longer → if speed increases Wavelengths get shorter→ if speed decreases

Sonographer Impact	
Wavelength is determined by **both** the machine and the medium the sound is traveling in. Wavelength cannot be adjusted by the sonographer. Shorter wavelengths improve axial resolution.	

Wavelength answers the question:

How much space does a cycle take up?

1 mm?
1 cm?
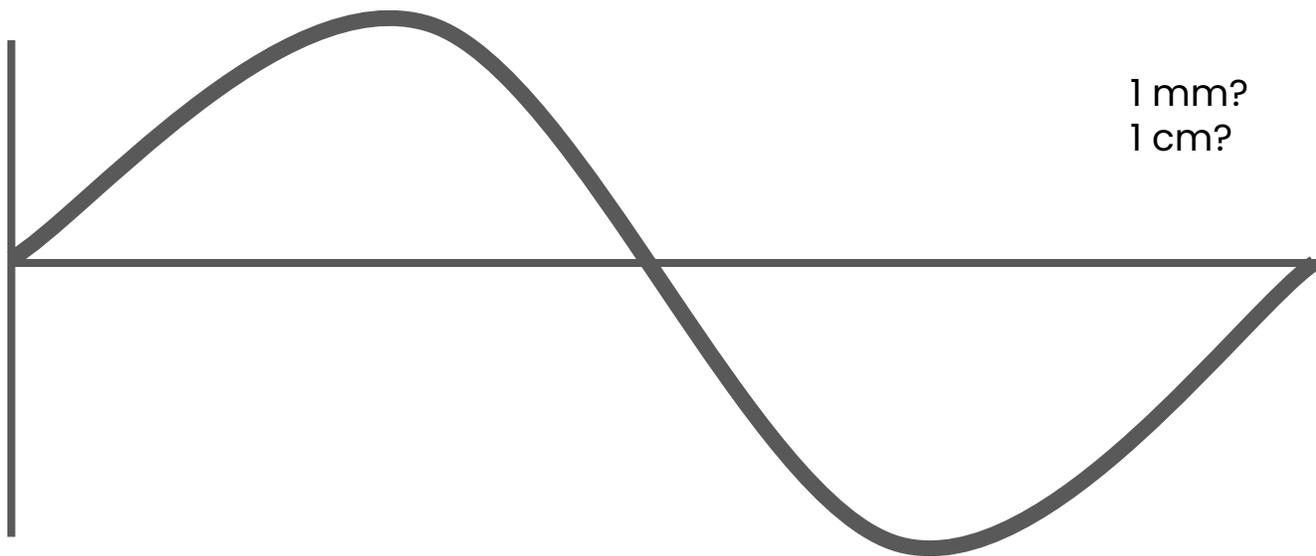
When presented with a graph, we can look at the distance label and count the cycles to determine the wavelength. In the above graph, there is only one cycle, so the wavelength is equal to whatever the axis is labeled.

9 mm
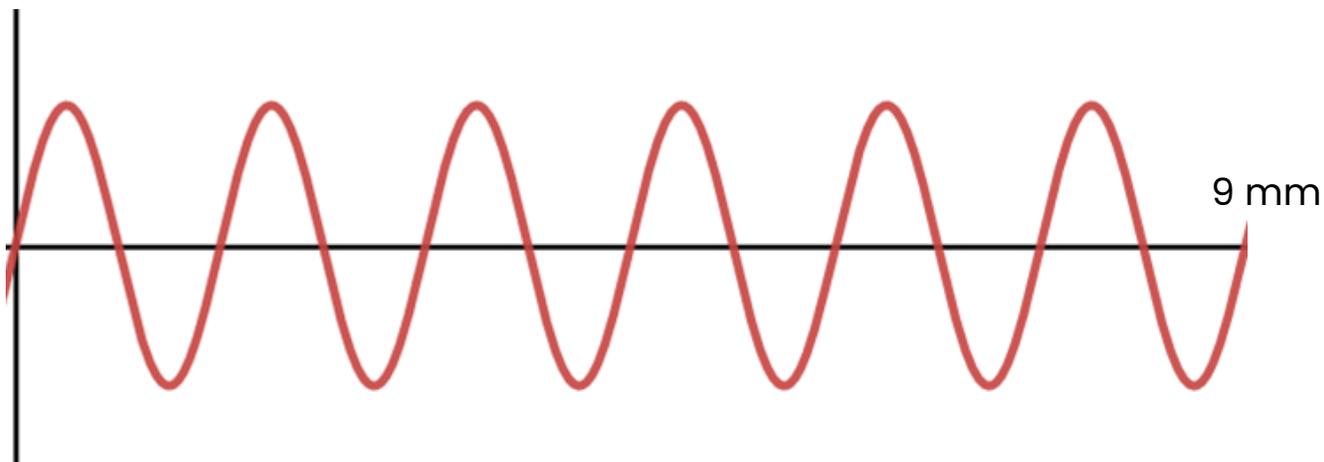
This graph has 6 cycles and a label of 9 mm. To determine the wavelength, you need to divide the labeled distance by the number of cycles (9 / 6). The wavelength of one cycle in this graph is 1.5 mm.

1.5 mm   1.5 mm   1.5 mm   1.5 mm   1.5 mm   1.5 mm
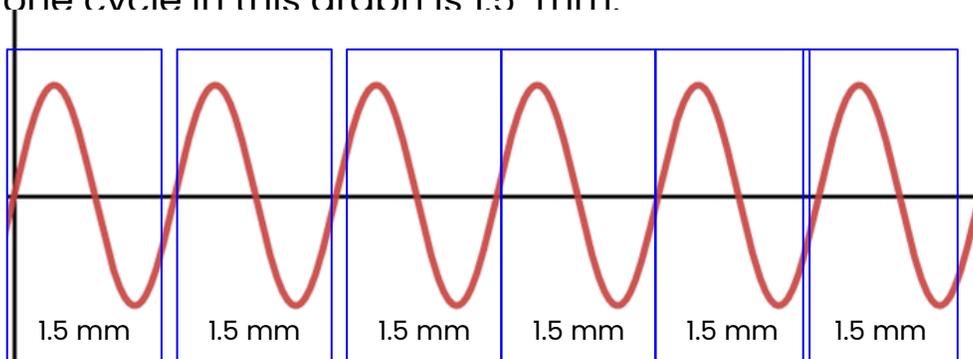
The frequency of the wave will affect the wavelength. Low frequencies have long wavelengths & high frequencies have short wavelengths.

This is an 8 MHz wave (top) and a 3 MHz wave (bottom). They are both representation of a wave for a duration of 1 microsecond. You can can see that the higher frequency has shorter wavelengths, compared to the low frequency.

1 microsec

1 microsec

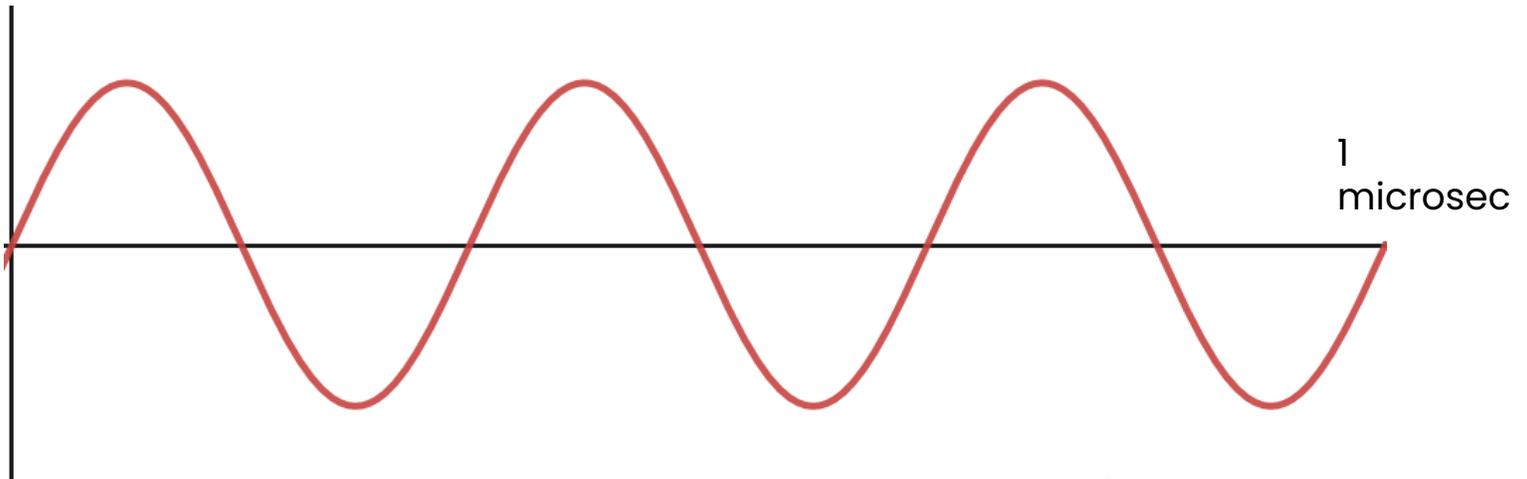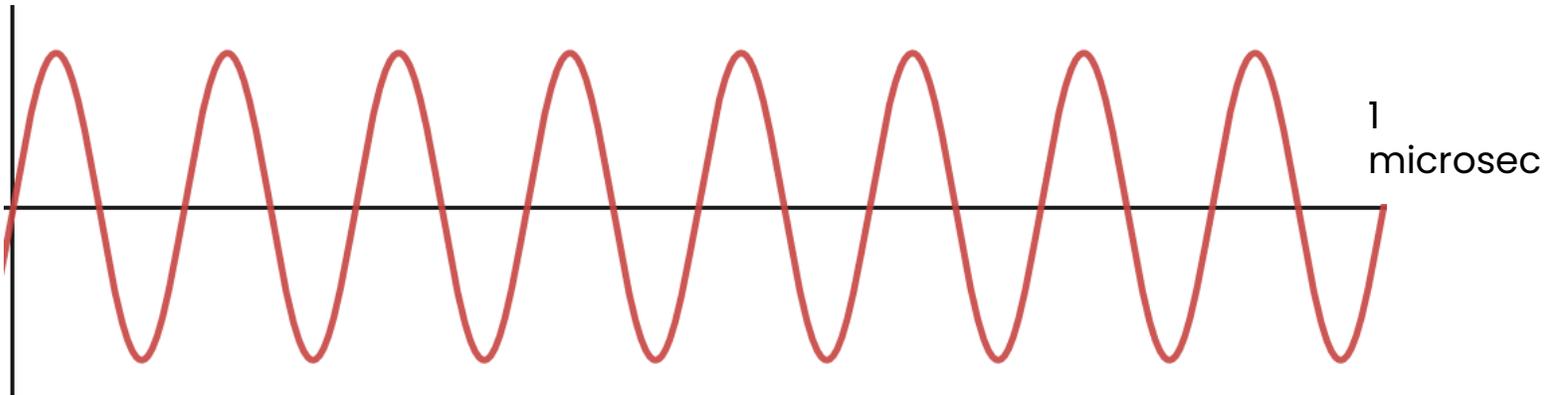However, we cannot calculate the wavelength with only information about the frequency. Wavelength is determined by the frequency of the wave and the medium in which is travels, so you need **both** pieces to calculate the wavelength.

If the graph is presented with a distance, wavelength can be calculated. If the graph is present with time, you need to know the speed of sound (based on the medium) to calculate the wavelength.

Using the above graphs, let's say they are traveling through air. The propagation speed of sound in air is REALLY slow at 330 m/s or 0.33 mm/μs.

Using 8 MHz and 3 MHz in the wavelength formula, we can calculate wavelength to be:

    0.4 mm wavelength in an 8 MHz wave traveling through air

    0.11 mm wavelength in a 3 MHz wave traveling through air

Using the general formula for wavelength:

$$\lambda \ (mm) = \frac{c \ (mm/\mu s)}{f \ (MHz)}$$

And replacing **c** with the propagation speed value

And **f** with the frequency in MHz, we can calculate any wavelength.

However, we are in ultrasound physics! We are going to replace **c** with a constant value of **1.54 mm/μs.** Whenever you see the phrase "traveling in soft tissue" or some variation of you will automatically know the propagation speed needed to calculate the wavelength.

Using the wavelength formula for soft tissue:

$$\lambda \ (mm) = \frac{1.54 \ (mm/\mu s)}{f \ (MHz)}$$

And substituting any frequency in MHz for **f,** you will now be able to calculate any wavelength for ultrasound values.

Using our previous example, if the 8 MHz wave and 3 MHz wave travel in soft tissue have wavelengths of:

   0.19 mm wavelength for an 8 MHz wave traveling in soft tissue

   0.51 mm wavelength for a 3 MHz wave traveling in soft tissue

0.19 mm

0.51 mm
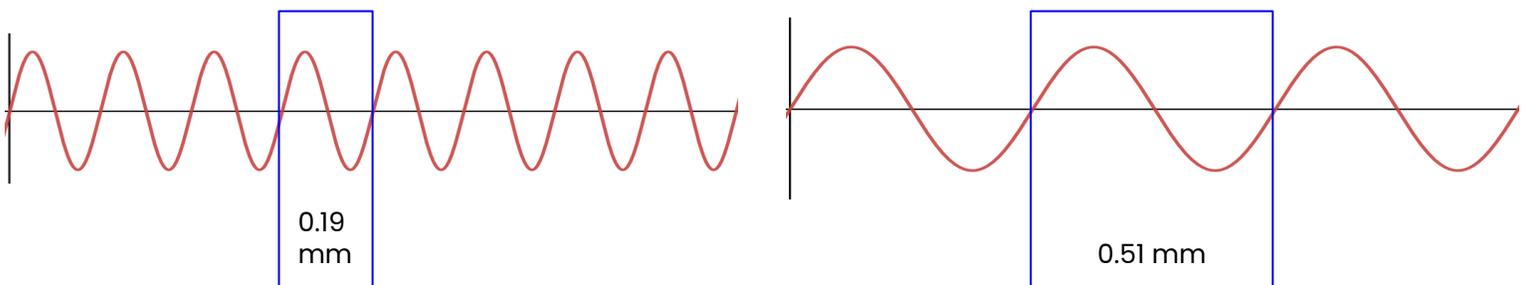
As this brief chart shows, as frequency increases, the wavelength decreases. A shorter wavelength means improved axial resolution. This is another reason we should use higher frequencies when the anatomy allows. Two values you should know off the top of your head are

Period	Frequency	Wavelength in Soft Tissue
1 μs	1 MHz	1.54 mm
0.5 μs	2 MHz	0.77 mm

3.2.3 Period, Frequency, Wavelength & Propagation Speed Review

★ If the math for the examples makes sense, you can skip the video lecture portion, otherwise make sure to watch the verbal/visual explanation.

This is a wave travelling in soft tissue. In this wave, this is one cycle:

From just this information, we can figure out the:

- Propagation speed
- Wavelength
- Frequency
- Period

With just using these 2 formulas:
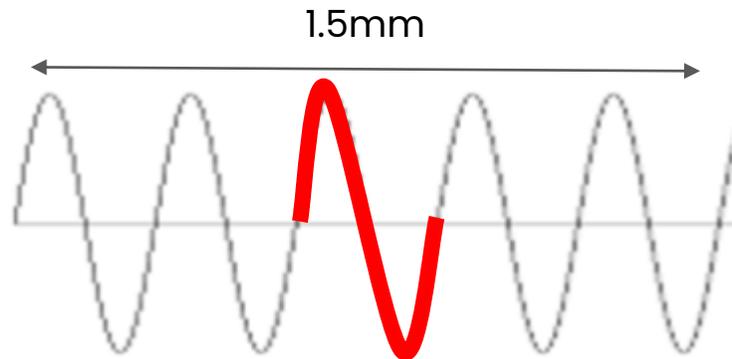
1.5mm

$$\lambda \ (mm) = \frac{1.54 \ (mm/\mu s)}{f \ (MHz)}$$

$$T(\mu s) = \frac{1}{f \ (MHz)}$$

Propagation speed is a constant in soft tissue. The value of propagation speed is 1540 m/s or 1.54 mm/μs.

Wavelength can be determined by counting the cycles (5) and dividing the length by the # of cycles. 1.5 mm/ 5 cycles = 0.3 mm.

Using the wavelength formula, we can transpose the formula to solve for frequency. Frequency = 1.54 (mm/μs) / 0.3 mm. Frequency = 5 MHz

Period is the reciprocal of 5 MHz or 1/5 MHz = 0.2μs

Propagation Speed	1.54 mm/μs.
Wavelength	0.3 mm
Frequency	5 MHz
Period	0.2μs

This time, I'm changing the label of the x-axis. This is not realistic Ultrasound value, but it still helps us to understand how the formulas work together and we get to convert some units!! Note the units used in the formulas for this example!

This is a wave travelling in soft tissue. In this wave, this is one cycle:
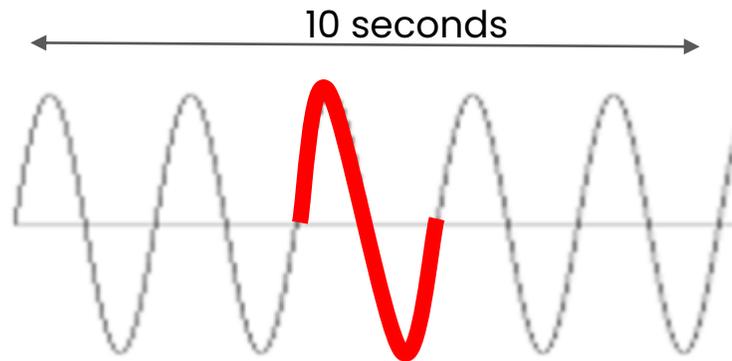
From just this information, we can figure out the:

- Propagation speed
- Period
- Frequency
- Wavelength

With just using these 2 formulas:

10 seconds

$$\lambda \ (m) = \frac{1540 \ (m/s)}{f \ (Hz)}$$

$$T(s) = \frac{1}{f \ (Hz)}$$

Propagation speed is still the same: 1540 m/s or 1.54 mm/μs (but let's use m/s because we're working in other base units.

We are best suited to figure out period first. We would take the total time and divide is by the # of cycles (5). 10 s/ 5 cycles = 2 seconds

Frequency is the reciprocal of 2 s, which = 1/2 …BUT we have to use matching units and because seconds is a base, we're going to use Hertz

Now here is where we have one more tricky spot to get through…we have Hertz as our unit for frequency, so we want to use complementary base units in our other formula, so we're going to calculate for a wavelength in meters.

Bonus Question: What type of sound is this? Ultrasound, Audible Sound or Infrasound?

Propagation Speed	1540 m/s
Period	2 s
Frequency	0.5 Hertz
Wavelength	3 080 m

Let's do one more example, but I'm changing the x-axis label again and the number of cycles. Hint - we're back to US values, so make sure your numbers make sense!

This is a wave travelling in soft tissue. In this wave, this is one cycle:
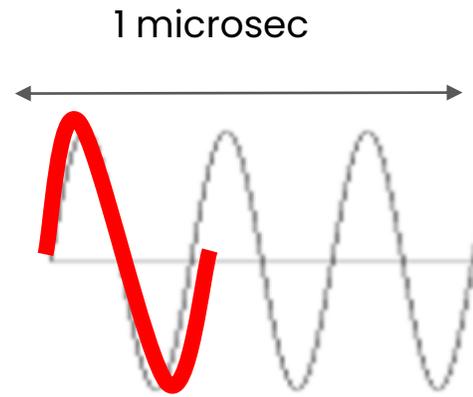
1 microsec

From just this information, we can figure out the:

- Propagation speed
- Frequency
- Period
- Wavelength

$$\lambda \ (mm) = \frac{1.54 \ (mm/\mu s)}{f \ (MHz)}$$

$$T(\mu s) = \frac{1}{f \ (MHz)}$$

With just using these 2 formulas:

Propagation speed is still the same: 1540 m/s or 1.54 mm/μs.

Now the number of cycles has changed as has the time frame. BUT, it is in a variation of 1 microsecond OR .000001 seconds. So we actually have the information to figure out period or frequency. This time though, we're going to start with frequency by counting. The fact that we have a "1 second" variation will allow us figure out the hertz easily by just counting the number of cycles. We have 3 cycles / 1 microsec = = 3 000 000 cycles / sec = 3 MHz.

To calculate the period, we can either take 1 microsec / 3 cycles OR we can do the reciprocal of 3 MHz . Either way, our period calculates to . ⅓ microsec or as a decimal 0.33 μs

Lastly, we need to calculate, wavelength. Plug in 3 MHz to the formula. 1.54 mm/μs / 3 MHz = 0.51 mm

Propagation Speed	1.54 mm/μs
Frequency	3 MHz
Period	0.33 μs
Wavelength	0.51 mm

The purpose of the 3 examples is to show you a few things:

1. A LOT of information can be derived from one piece of information, if you know your formulas.

2. A basic image of a wave changes the wave parameters drastically based on labels. Always check axis labels.

3. Units in formulas are important! We would have had a very wrong answer in Example 2 if we left our frequency in Hertz.

4. This is probably way more math than you'll need to do in one setting but this might be an actual question:

What is the wavelength of a 3 MHz wave, traveling in soft tissue?

a. 3 mm
b. 3 m
c. 0.5 mm
d. 0.05 km

C. is correct. 1.54 mm/us / 3 MHz = 0.51 mm

3.2.3 Period, Frequency, Wavelength & Propagation Speed- Practice

Fill in the chart for these common Ultrasound values given the information:

Common Ultrasound Values in soft tissue:			
Period	Frequency	Wavelength	Propagation Speed
	1 MHz		
		0.77 mm	1.54 mm / µs
0.29 µs			
	5 MHz		
		0.21 mm	
0.1 µs			
		0.10 mm	

Section 3.3 Strength Parameters

Section 3.1 told us that:

- Period & Frequency are reciprocals
- That both period and frequency are controlled by the machine/transducer
- Neither period or frequency can be adjusted by the sonographer.

Section 3.2 told us that:

- Wavelength is dependent on the machine AND the medium
- Propagation speed is depend on ONLY the medium
- Neither medium can be adjusted by the sonographer

There are 3 more parameters to cover and they describe the strength, size or "bigness" of the wave. They are Amplitude, Power & Intensity.   You should know that:

- All 3 parameters are directly related to one another
- All 3 parameters are determined by the machine
- All 3 parameters can be adjusted by the sonographer by adjusting the machine's output power
- All 3 parameters will weaken (attenuate) as they propagate through the body

In this section, you will see this symbol : $\propto$ this should be read as "is proportional to"

3.3.1 Amplitude

Definition	
The **difference between the average value of an acoustic variable & its maximum** (or minimum) pressure change / density change / distance change.	

Symbol	Units
A	Pascals (Pa), g/cm³, mm or decibels (dB) The three ways amplitude can be expressed are as changes in the three acoustic variables: Pressure, density, and motion. . Pressure, is the most common US amplitude discussed and ranges from 1 to 3 MPa (1-3 million Pa).

Formulas	Relationships
$$P \propto A^2$$ $$I \propto A^2$$	<u>Power is proportional to amplitude squared:</u> <u>Intensity is proportional to amplitude squared</u> If amplitude increases by a factor → Power & intensity both increase by that factor squared. If amplitude decreases by a factor → Power & intensity both decrease by that factor squared

Sonographer Impact	
Amplitude is determined by the output power of the machine, but weakens with propagation. The sonographer can adjust amplitude by adjusting the output power.	

Amplitude is one way to describe the **strength** of a wave.

Amplitude is measured by determining the change of an acoustic variable from its resting (or neutral) position when no sound wave is present to the max compression or max rarefaction. (Yellow Arrows)

+ pressure, density or motion change

Neutral position

– pressure, density or motion change
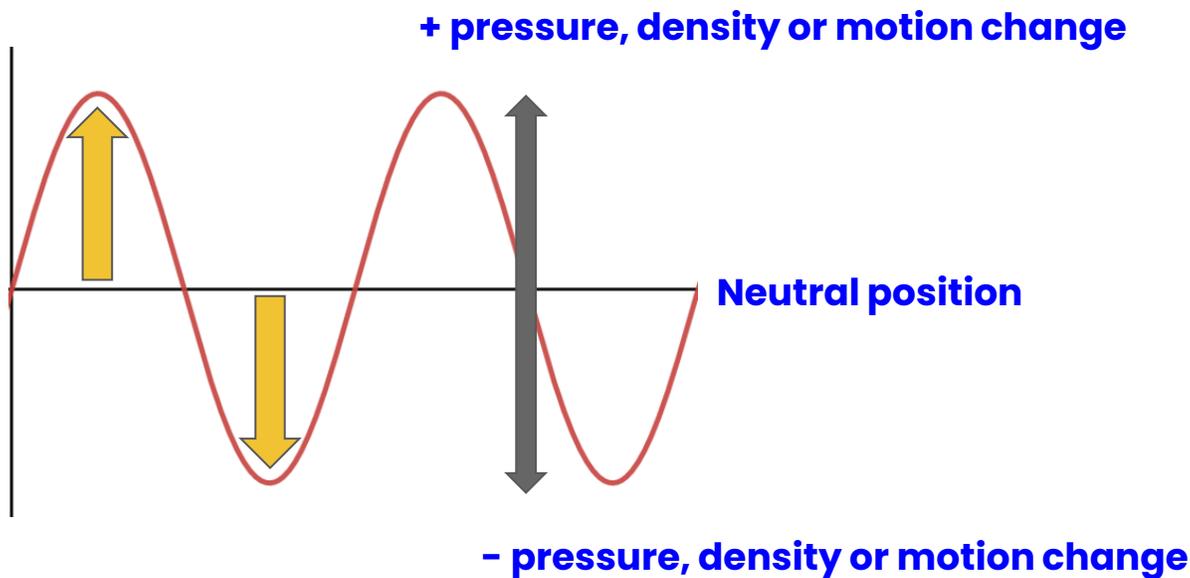
Amplitude can (but rarely) also be discussed as a peak-to-peak amplitude. Amplitude is ½ the peak-to-peak amplitude. (Gray Arrow).

Waves with the same frequencies can have different amplitudes. The amplitude typically translates to loudness to human ears for audible sounds.

The strength of the wave in ultrasound will affect the brightness of the echoes and bioeffects. If we could hear ultrasound it would be the loudness as well.
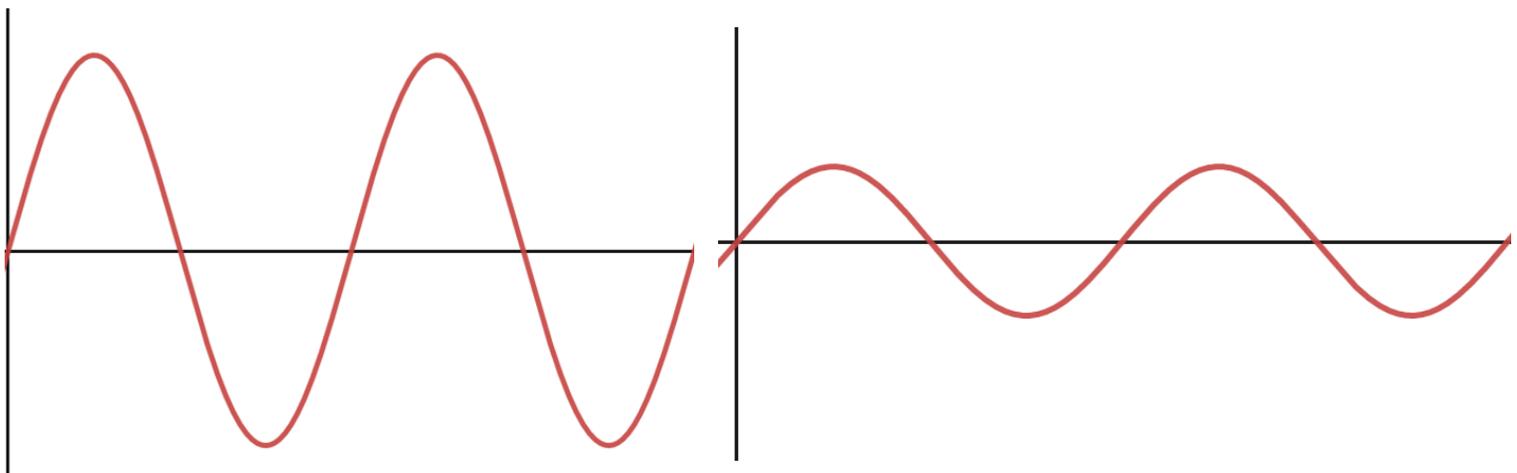
3.3.2 Power

Definition
The rate of work or **energy transfer** Lightbulbs can help us to understand power. When a lightbulb has a higher watt, it is a brighter bulb. This is because there is more energy transferred into light energy, which makes it brighter.

Symbol	Units
P	Milliwatts (mW) or Watts (W) Power is determined by the machine, based on the output power. Dependent on the setting chosen by the sonographer, the power of a wave typically ranges from 4 to 90 milliwatts.

| Formulas	Relationships
$P \propto A^2$ $P \propto I$	<u>Power is proportional to amplitude squared:</u> <u>Power is proportional to intensity:</u> If amplitude increases by a factor → Power & intensity both increase by that factor squared. If amplitude decreases by a factor → Power & intensity both decrease by that factor squared If power increases by a factor → intensity increases by the same factor

Sonographer Impact
Power is determined by the output power of the machine, but weakens with propagation. The sonographer can adjust power by adjusting the output power.

3.3.3 Intensity

Definition	
Concentration of energy in the sound beam. The power put out by a machine will affect the intensity of the beam as will the area of the beam. In general, more power or less area will make a strong beam. Less power or more area will cause the beam to be less intense.	

Symbol	Units
I	Watts/ square centimeters (W/cm²)

Formulas	Relationships
$$I \propto A^2$$ $$P \propto I$$ $$I\ W/cm^2 = \frac{P\ (W)}{Area\ (cm^2)}$$	<u>Intensity is proportional to amplitude squared</u> If amplitude increases by a factor → Power & intensity both increase by that factor squared. If amplitude decreases by a factor → Power & intensity both decrease by that factor squared <u>Power is proportional to intensity</u> If power increases by a factor → intensity increases by the same factor <u>Intensity is directly related to power & inversely related to area</u> If Intensity gets stronger→ Power gets stronger OR area narrowed If intensity weakens→ Power weakened OR are became wider

Sonographer Impact

Intensity is determined by the output power of the machine, but weakens with propagation.
The sonographer can adjust intensity by adjusting the output power.

3.3.4. Strength Parameter Review

★ If the math for the examples makes sense, you can skip the video lecture portion, otherwise make sure to watch for verbal/visual explanation.

We covered the concepts that:

$$P \propto A^2$$

→ **Power is proportional to amplitude squared.**

$$I \propto A^2$$

→ **Intensity is proportional to amplitude squared.**

→ **Power is proportional to intensity.**

$$P \propto I$$

When we are considering how the values change in relation to one another keep these rules in mind:

- Increasing by a factor means to multiple
- Decreasing by a factor means to divide
- When amplitude increases by a factor, power and intensity will increase by that factor squared
    - If A increases by a factor of 2, P & I increase by a factor of 4
    - If A increases by a factor of 3, P & I increase by a factor of 9
    - If A increases by a factor of 4, P & I increase by a factor of 16
    - etc.
- When amplitude decrease by a factor, power and intensity will decrease by that factor squared
    - If A decreases by a factor of 2, P & I decrease by a factor of 4
    - If A decreases by a factor of 3, P & I decrease by a factor of 9
    - If A decreases by a factor of 4, P & I decrease by a factor of 16
    - Etc.
- When power increases or decreases by a factor, intensity will increase or decrease by the same factor.
- Common phrases:
    - Doubling is the same as increasing by a factor of 2
    - Halving is the same as decreasing by a factor of 2
    - Quadrupling is the same as increasing by a factor of 4
    - Quartering is the same as decreasing by a factor of 4
    - Decreasing by a factor may be phrased as making something a fraction as strong.
        - For example, amplitude is halved, power is ¼ as strong
    - Decreasing by a factor can also be termed as reduced by a fraction
        - For example decreasing by a factor of 4 is the same as reducing by ¼

Examples:

Let's assume we start with these original values:

The intensity of the wave is 5 mW/cm^2

The power of the wave is 25 mW

The amplitude of the wave is 1.2 MPa.

If amplitude increased by a factor of 2, what happens to intensity & power?

Original Intensity	5 mW/cm^2	x 4	New Intensity	20 mW/cm^2
Original Power	25 mW	x 4	New Power	100 mW
Original Amplitude	1.2 MPa	x 2	New Amplitude	2.4 MPa

If amplitude decreased by a factor of 2, what happens to intensity & power?

Original Intensity	5 mW/cm^2	÷ 4	New Intensity	1.25 mW/cm^2
Original Power	25 mW	÷ 4	New Power	6.25 mW
Original Amplitude	1.2 MPa	÷ 2	New Amplitude	0.6 MPa

If amplitude increased by a factor of 3, what happens to intensity & power?

Original Intensity	5 mW/cm^2	x 9	New Intensity	45 mW/cm^2
Original Power	25 mW	x 9	New Power	225 mW
Original Amplitude	1.2 MPa	x 3	New Amplitude	3.6 MPa

If amplitude decreased by a factor of 3, what happens to intensity & power?

Original Intensity	5 mW/cm^2	÷ 9	New Intensity	0.56 mW/cm^2
Original Power	25 mW	÷ 9	New Power	2.78 mW
Original Amplitude	1.2 MPa	÷ 3	New Amplitude	0.4 MPa

If intensity increases to 80 mW/cm² what are the new values of power and amplitude?				
Original Intensity	5 mW/cm²	x 16	New Intensity	**80 mW/cm²**
Original Power	25 mW	x 16	New Power	400 mW
Original Amplitude	1.2 MPa	x 4	New Amplitude	4.8 MPa

If power decreases to 1.56 mW, what are the new values of intensity and amplitude?				
Original Intensity	5 mW/cm²	÷ 16	New Intensity	0.31 mW/cm²
Original Power	25 mW	÷ 16	New Power	**1.56 mW**
Original Amplitude	1.2 MPa	÷ 4	New Amplitude	0.3 MPa

The key takeaways:

1. Power and Intensity are proportional to **amplitude squared.**

2. Power and intensity are proportional to one another and increase/decrease by the factor.

3. Note that NONE of these parameters are related to period, frequency, wavelength or propagation speed.

4. This is probably way more math than you'll need to do in one setting but this might be an actual question:

    The amplitude of a wave increase from 4 MPa to 8 MPa. What happened to power?

    a. It doubled
    b. It halved.
    c. It quadrupled.
    d. It quartered.

    C. is correct. A increased 2x, P increases 4x

3.3.4 Strength Parameter Review - Practice

 Fill in the chart given the information:

	Original Value		New Values
Intensity	10 mW/cm²	Intensity	
Power	36 mW	Power	
Amplitude	3 MPa	Amplitude	**9 MPa**
Intensity	18 mW/cm²	Intensity	
Power	58 mW	Power	
Amplitude	3.6 MPa	Amplitude	**0.9 MPa**
Intensity	1 mW/cm²	Intensity	
Power	3 mW	Power	**75 mW**
Amplitude	2 MPa	Amplitude	
Intensity	180 mW/cm²	Intensity	**5 mW/cm²**
Power	540 mW	Power	
Amplitude	12 MPa	Amplitude	

Section 3.5 Summary

Amplitude Power Intensity

Amplitude (MPa), Power (mW) & Intensity (w/cm²)
- Controlled by machine & sonographer, but attenuate in the body
- All directly related to one another

Period (μs) & Frequency (MHz)
- Reciprocals f x T = 1
- Controlled by machine, cannot be adjusted

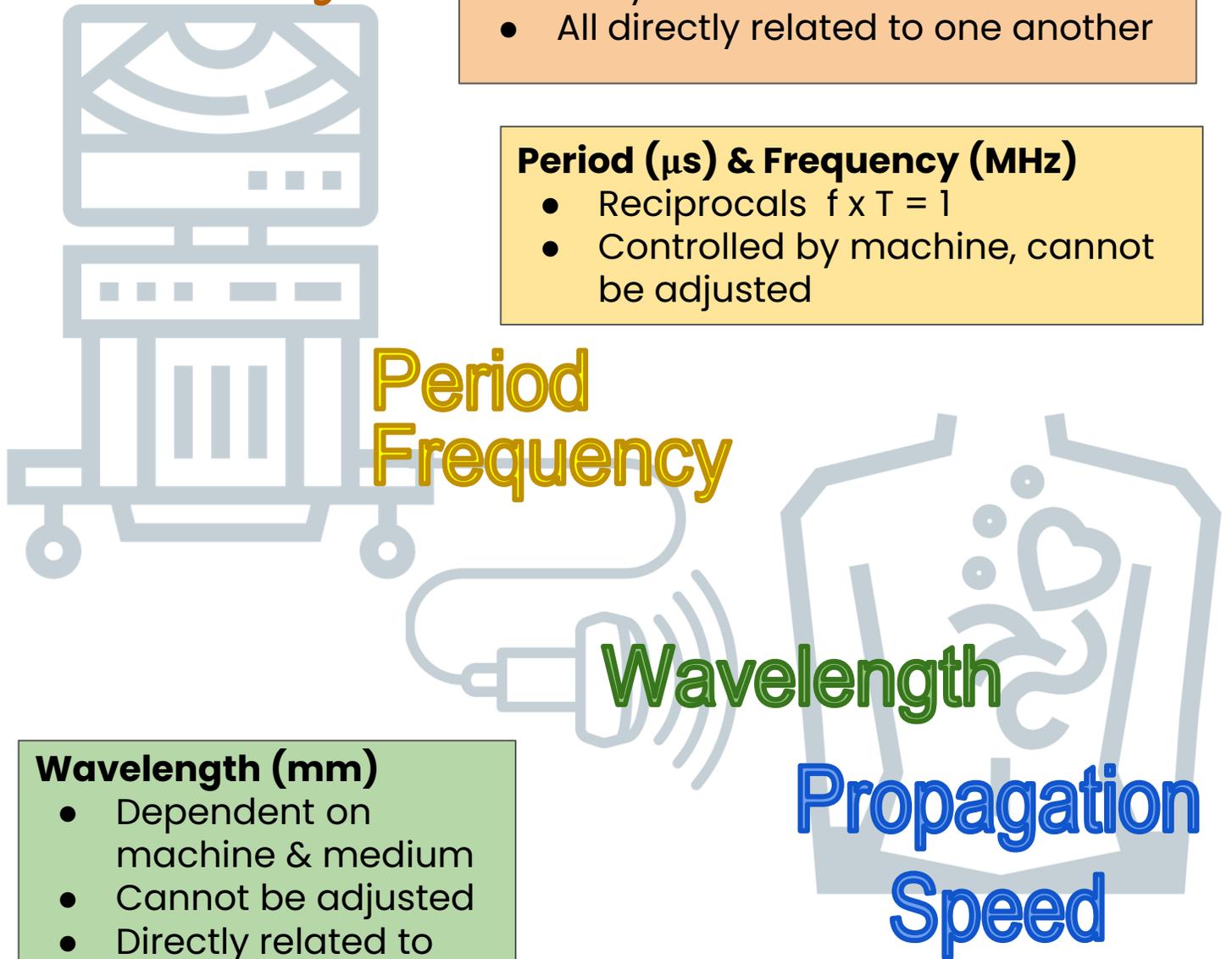**Period Frequency**

Wavelength

Propagation Speed

Wavelength (mm)
- Dependent on machine & medium
- Cannot be adjusted
- Directly related to speed, inversely related to frequency
  $\lambda = c/f$

Propagation Speed (m/s)
- Solely dependent on medium
- Cannot be adjusted
- 1540 m/s in soft tissue
- Directly related stiffness, inversely related to density

← Answer Link

1. How are these items related?

(U)nrelated   (D)irectly (I)nversely   (R)eciprocals

	Frequency & Propagation Speed
	Power & Speed
	Power & Intensity
	Period & Frequency
	Frequency & Wavelength
	Density & Speed
	Stiffness & Speed
	Frequency & Amplitude
	Amplitude & Intensity
	Propagation Speed & Period
	Wavelength & Power
	Area & Intensity
	Wavelength & Period

2. Using the wave profile, complete the chart:
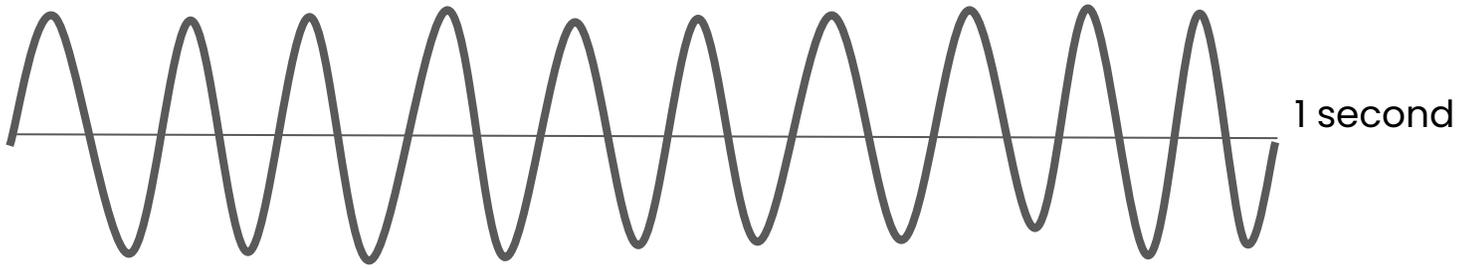
1 second

Medium:	Soft Tissue
Propagation Speed	
Frequency	
Period	
Wavelength	

3. Using the wave profile, complete the chart:

4 microsec
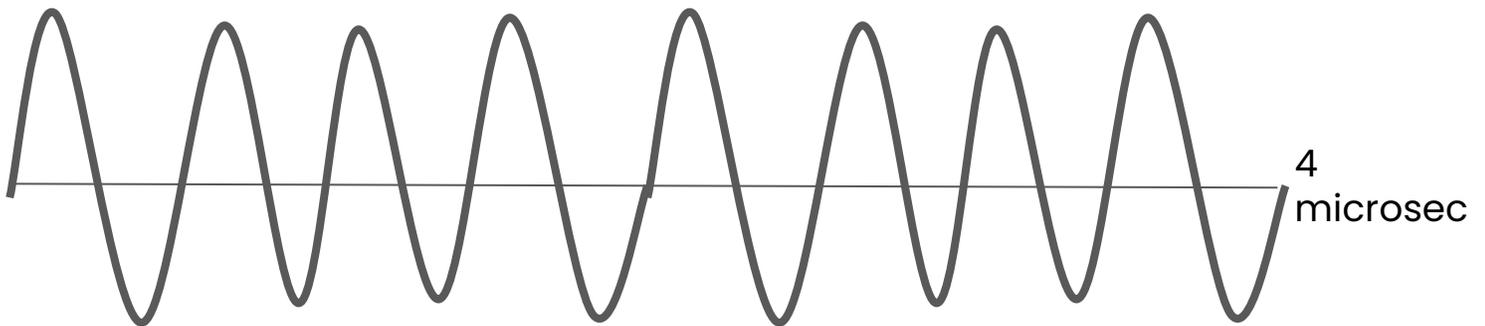
Medium:	Soft Tissue
Propagation Speed	
Frequency	
Period	
Wavelength	

2. Using the wave profile, complete the chart:
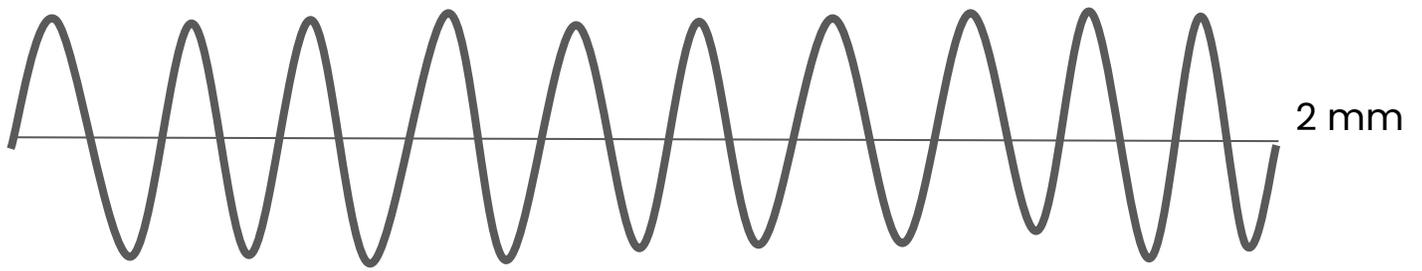
2 mm

Medium:	Soft Tissue
Propagation Speed	
Frequency	
Period	
Wavelength	

3. Using the wave profile, complete the chart:

10 mm
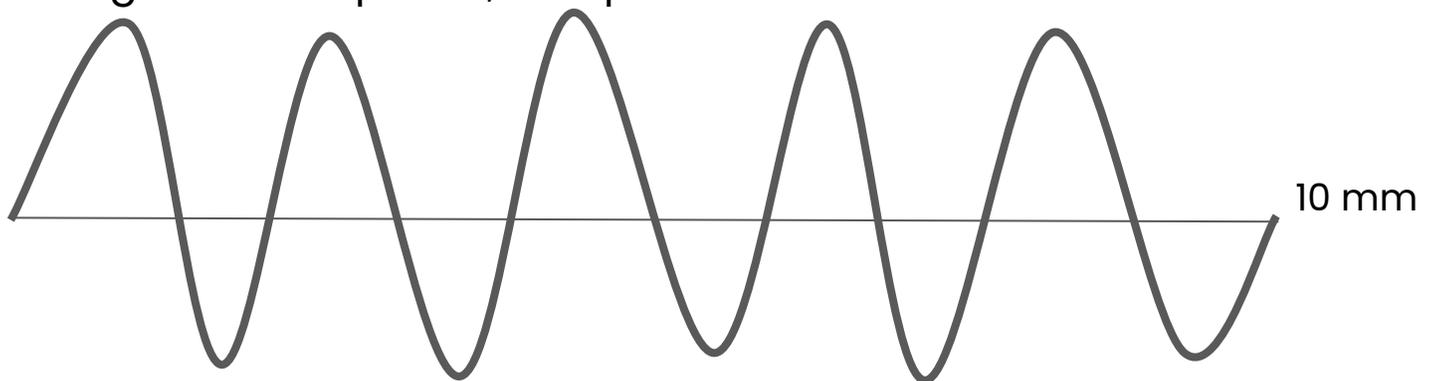
Medium:	AIR
Propagation Speed	
Frequency	
Period	
Wavelength	

3. Calculate the complimentary unit reciprocals, report in decimal form, to the nearest 0.001 & units:

Frequency = 5 MHz	Period =	
Frequency = 7 Hz	Period =	
Frequency = 1000 kHz	Period =	
Frequency = 12 MHz	Period =	

4. Sort these frequencies as infrasound, audible or ultrasound.

Infrasound _____ Audible _____

_____ Ultrasound _____

5 MHz   20 kHz   10 Hz   20,000 Hz   21 kHz   1000 Hz

5. Fill in the missing pieces of the chart:

Variable	Original Value	New Value
Amplitude	60 mm	30 mm
Power	24 Watts	
Intensity		4 W/cm²

6. Fill in the missing pieces of the chart:

Variable	Original Value	New Value
Amplitude	100 Pa	
Power	50 W	450 W
Intensity	13 W/cm²	

7. Fill in the missing pieces of the chart:

Variable	Original Value	New Value
Amplitude		60 g/cm³
Power		80 W
Intensity	16 W/cm²	64 W/cm²

8. Complete the missing spaces in the chart, assuming soft tissue. Round to the nearest 0.001 and don't forget units!

Frequency	Period	Wavelength
		0.5 mm
	0.125 µs	
12 MHz		
5 MHz		
	0.066 µs	
		0.25 mm

9. Place an "X" next to the medium that sound will travel through the FASTEST.

Which is faster?	Medium			Which is faster?
	Lung	or	Bone	
	Air	or	Water	
	Liver	or	Fat	
	Bone	or	Muscle	
	Air	or	Space	
	Marshmallow	or	Rock	

3.7 Nerd Check!

1. What are the 7 parameters of a sound wave
2. What special relationship to period and frequency have?
3. How would you describe a cycle?
4. What is the definition of period?
5. What are the units of period?
6. What is the formula for period?
7. Can period be changed by the sonographer?
8. How are period and frequency related?
9. What is the definition of frequency?
10. What are the units of frequency?
11. What are 2 formulas you learned that equal frequency?
12. How is frequency controlled?
13. How does the sonographer choose the best frequency?
14. What are the ranges for ultrasound, audible sound and infrasound?
15. How many cycles per second is one hertz? One kilohertz? One megahertz?
16. How are period and frequency related?
17. How are frequency and wavelength related?
18. Can frequency be adjusted by the sonographer?
19. Why are high frequencies good?
20. Why are high frequencies bad?
21. Which parameter answers the question how many cycles can occur in 1 second?
22. Which parameter answers the question how much time does it take to complete 1 cycle?
23. What is the definition of propagation speed?
24. What are the units for propagation speed?
25. What determines how fast sound travels?
26. How can you change the propagation speed?
27. What is the propagation speed in soft tissue?

28. How did the propagation speed of soft tissue get figured out?
29. Put these in order of slowest speed to fastest: Bone, Liver, Air, Soft Tissue, Water, Fat
30. How are propagation speed and stiffness related?
31. How are propagation speed and density related?
32. WHich has a bigger effect on propagation speed, density or stiffness?
33. What does stiffness mean?
34. What are other names for stiffness?
35. What is an example of something that is stiff? Not stiff?
36. What is density?
37. What is an example of something dense? Not dense?
38. What is the definition of wavelength?
39. What are the units of wavelength?
40. What is the formula for wavelength?
41. What is the formula for wavelength in soft tissue?
42. What determines the wavelength?
43. Can the wavelength be adjusted?
44. Why are short wavelengths better?
45. How are frequency and wavelength related?
46. How are wavelength and propagation speed related?
47. What is the wavelength of a 1 MHz transducer? 2 MHz?
48. What are the 3 parameters that describe the strength of a wave?
49. What is the definition of amplitude?
50. What variables change to measure amplitude?
51. How is amplitude related to power and intensity?
52. Can amplitude be adjusted?
53. What happened to amplitude as a wave travels through the body?
54. What is peak to peak amplitude?
55. What would cause a bigger amplitude?
56. What units is amplitude measured in?
57. What is the most common unit of amplitude?

58. What is the definition of power?
59. What are the units of power?
60. What is power related to amplitude and intensity?
61. What determines the power?
62. Can power be adjusted?
63. What happen to power in the body?
64. What is the definition of intensity?
65. What are the units of intensity?
66. What is the formula for intensity?
67. How is intensity related to amplitude and power?
68. How are power, intensity and amplitude related to frequency, period, wavelength and propagation speed?
69. If amplitude increases by a factor of 2, how much does power increase?
70. If amplitude decreases by a factor of 3, how much does intensity decrease?