Name: ______________________________

Other group members: ______________________________

Tutorial #2

PHYS 1240: Sound and Music

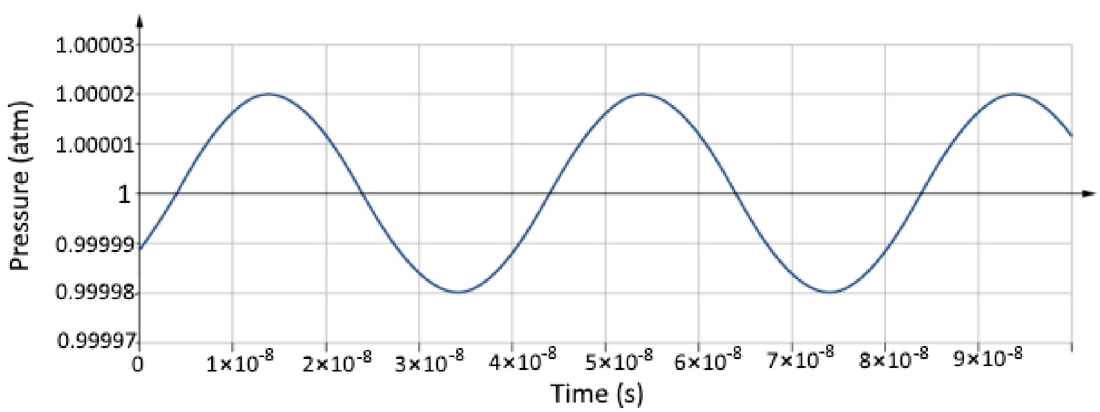
Friday, July 12, 2019

Instructions: Work in groups of 3 or 4 to answer the following questions. Write your solutions on this copy of the tutorial—each person should have their own copy, but make sure you agree on everything as a group. When you're finished, keep this copy of your tutorial for reference—no need to turn it in (grades are based on participation, not accuracy).

Ultrasound: The human ear can hear a range of frequencies from 20 Hz to about 20,000 Hz. Any sound with a frequency above this range is called *ultrasound*. Here we will examine some of the medical applications of ultrasound technology.

1. The plot at the bottom of this page shows an example of an ultrasound wave used for medical diagnostics.

   a) What is the amplitude (the maximum pressure difference from equilibrium) of this ultrasound wave, in units of atmospheres? What is this in pascals?

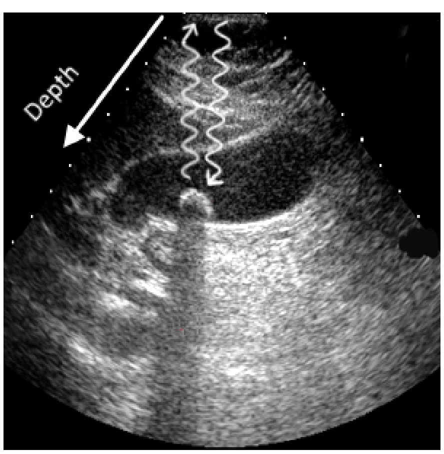


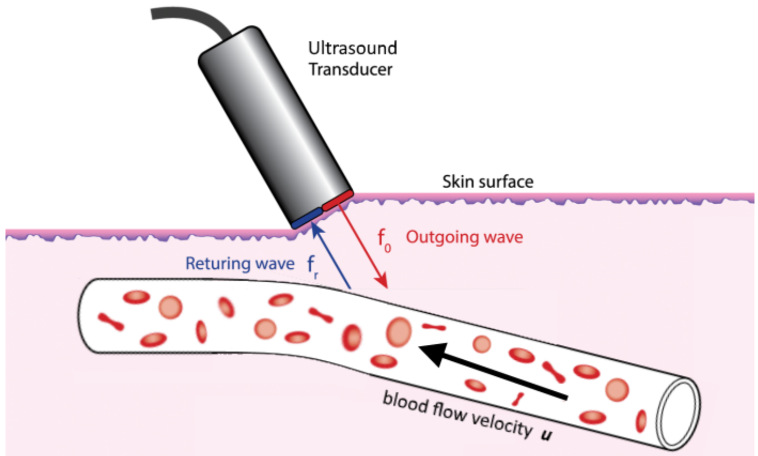
b) Once again referring to the wave shown at the bottom of the previous page, what is the ultrasound's period? Convert this to a frequency, expressing your answer in MHz (megahertz).

c) The ultrasound wave you're analyzing is sent into a human body. Since soft tissue in humans has a high water content, it is a good approximation to say that the speed of sound in tissue is equal to the speed of sound in water (about 4.5 times the speed in air at 20°C). What is this speed, in m/s?

d) The smallest resolution an ultrasound signal can observe is approximately equal to the size of the signal's wavelength. Assuming the wave has the frequency found in part (b) and travels at the speed found in part (c), find the wavelength, and therefore the size of the smallest detail observable in human tissue with this ultrasound. Is this enough to detect a 2 mm gestational sac a few weeks after conception?

e) Ultrasounds used in imaging detect the depth of objects in the body by sending waves in and measuring how long it takes for the waves to reflect and return to the detector. If the time delay between the sending out and the detection of a reflected ultrasound wave traveling through a piece of soft tissue was 0.16 ms, at what depth did this reflection occur, in centimeters?





2. Ultrasounds can be used to measure the flow of blood by combining the phenomena of beats with the Doppler effect, just like a police's radar gun. To see how this works, consider an ultrasound pulse with a frequency of $f_0 = 2.5\times10^6$ Hz that is sent through human tissue toward a blood vessel, as shown above.

   a) If we treat the blood as a moving observer with speed $u = 0.2$ m/s, moving as shown above, will the frequency received by the blood be greater than or less than f_0? What is the percent change in this frequency? Assume the speed of the ultrasound pulse is the same as what you calculated in part (c) of the previous problem.

   b) Once the ultrasound pulse reflects off of the blood, it returns to the ultrasound device and is detected by a microphone. If we treat the blood now as a moving source and the microphone as a stationary detector, we see that the ultrasound pulse will be Doppler-shifted a second time. Will the ultrasound received by the microphone be greater than or less than the wave sent from the blood? Calculate the percent change in frequency.

c) Calculate the frequency f_r received by the microphone using your percent changes above. To do this, first add your two percent changes together to find the total percent change from f_0 to f_r. Then, multiply this total percent change by the initial frequency to find how much the returning frequency gets shifted up or down (for example, if the total percent change is 15% and the pitch should increase, then $f_r = f_0 + (0.15 f_0)$, while if the pitch should decrease, $f_b = f_0 - (0.15 f_0)$.

d) Since the ultrasound received by the microphone is such a high frequency, it isn't practical to measure the returning frequency directly. Instead, the microphone measures the beat frequency from the mixed patterns of the source and returning frequencies. In this case, what is the beat frequency? Is this something you can hear (i.e. is it within the audible range of human hearing)?